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STUDIES WITH SWEET CORN

II. SOWING DATES AND PLANT CHARACTERS

GORDON HASKELL

(*John Innes Horticultural Institution, Merton Park, London, S.W.19.*)[1]

LITTLE is known of the influence of the English climate on the behaviour of sweet corn. An investigation was therefore made to determine what effects sowing at different times had on the final crop.

Mather and Haskell [1] have already shown that early sowings greatly reduce germination; sowings made between April and May give highest germination. If earlier sowings produce earlier crops in spite of reduced germination it might be worth sowing heavily to get the more valuable early harvests.

Experimental methods.—Six varieties were used. These included: Extra Early Bantam (EEB) and Canada Gold (CG) as controls, Golden Sunshine (GS), Plumptip (P or p), Dependogold (D), and the white seeded Early White Market (EWM). The varieties were sown in two plots at 28-day intervals from March 1, 1946, viz. March 1, March 28, April 26, and May 24. Twenty-two seeds were sown singly a foot apart in the row. Each plot had 24 rows spaced 2 ft. apart, the position of each variety per sowing date being randomized for each. Row averages were obtained from individual plant measurements. Plot means were used for recording the data.

Effects of Sowing Time

(i) *Flowering time and maturity.*—Earliness was measured by (*a*) mean tasselling time and (*b*) mean silking time, both in days from July 1. These values are given in Figs. 1 and 2 respectively. Extra Early Bantam, Canada Gold, and Early White Market flowered earliest. The March 1 and 28 plants flowered more or less at the same time; in some instances, e.g. Extra Early Bantam and Canada Gold, the March 28 plants silked slightly earlier. April 26 and May 24 plants flowered somewhat later but not at 56 and 84 days after those of March 1, as expected if flowering is directly proportional to sowing time. The broken lines in Figs. 1 and 2 indicate the directions for the expected flowerings of Canada Gold. Protandry was independent of sowing date (Fig. 3).

Maturity of each row was measured by the date when first ripe marketable ears were picked off main stems (Fig. 4). Both March sowings gave somewhat similar picking dates, April 26 were slightly later and May 24 somewhat later still. The graph of days from sowing to flowering plotted against sowing date (Fig. 5) shows there is a steady decrease in the time taken by the plants to come into flower. Later sowings flowered proportionally quicker than earlier ones. This is similar to what Singleton

[1] Now at Bayfordbury, Hertford, Herts.

[Empire Journ. of Exper. Agric., Vol. 18, No. 69, 1950.]
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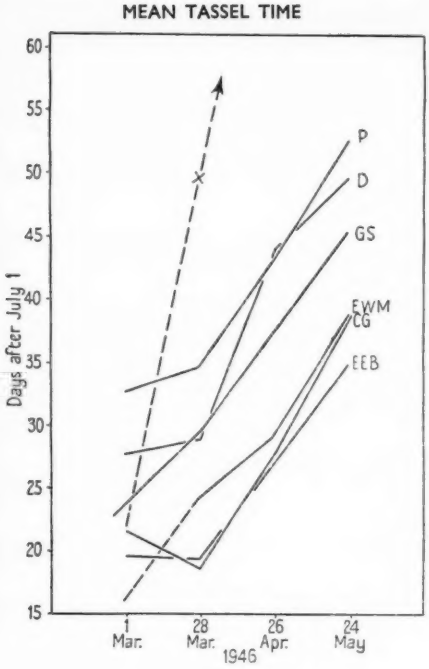

FIG. 1

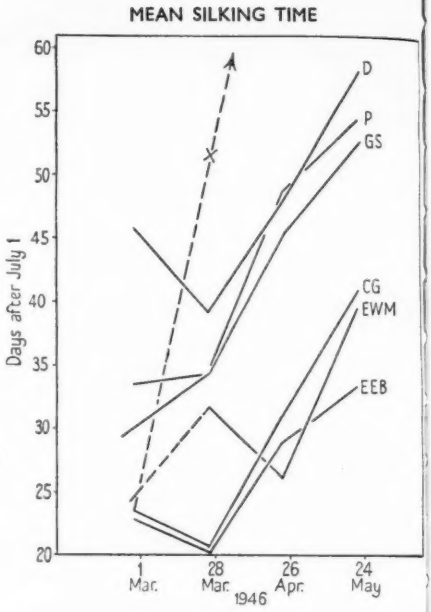

FIG. 2

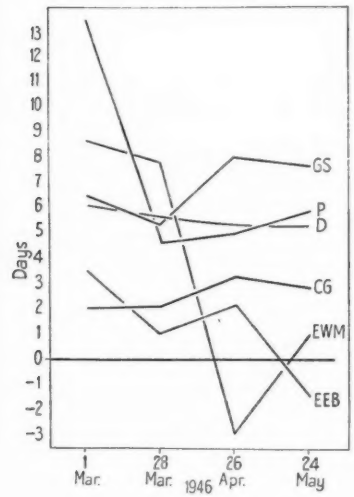

FIG. 3

FIG. 1. Effect of sowing time on tasselling time (pollen shedding) of six sweet corn varieties. Mean tasselling time (in days after July 1) plotted against sowing date.

Key to Varieties

CG	Canada Gold.	EWM	Early White Market.
D	Dependogold.	GS	Golden Sunshine.
EEB	Extra Early Bantam.	P or p	Plumptip.

FIG. 2. Effect of sowing time on dates when six varieties of sweet corn produced silks. Mean silking time (in days after July 1) plotted against sowing date.

Key to Varieties. As for Fig. 1.

FIG. 3. Effect of sowing time on the protandry of six sweet corn varieties. Differences between mean tasselling times and mean silking times plotted against sowing date.

+ values indicate protandry; — values indicates protogyny.

Key to Varieties. As for Fig. 1.

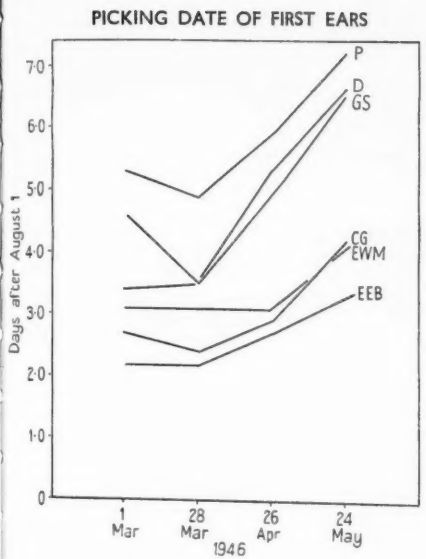

FIG. 4

Effect of sowing time on harvesting of six varieties of sweet corn. Mean picking date of first ears (in days after Aug. 1) plotted against sowing date.

Key to Varieties. As for Fig. 1.

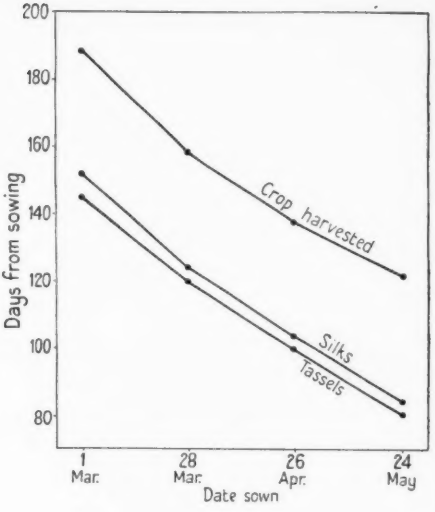

FIG. 5

The effect of sowing time on the time taken by six sweet corn varieties to flower and to produce mature ears for market. Number of days from sowing to tasselling, silking, and maturity (means for six varieties) plotted against sowing date.

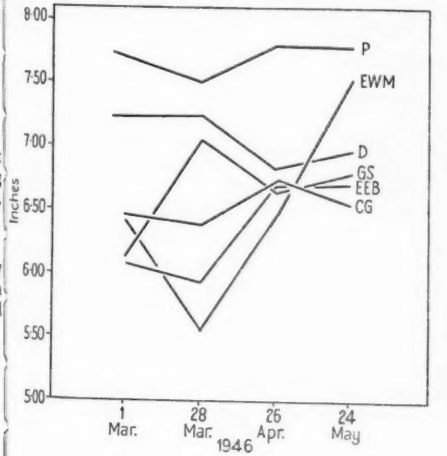

FIG. 6

Effect of sowing time on-ear length of six sweet corn varieties. Mean ear-length (in inches) of first marketable ears from main stems plotted against sowing date.

Key to Varieties. As for Fig. 1.

[2] has found in Connecticut. However, differences between both tasselling and silking dates and that for maturity remain constant regardless of sowing date. Flowering measurements are therefore good indicators of when the crop will be picked.

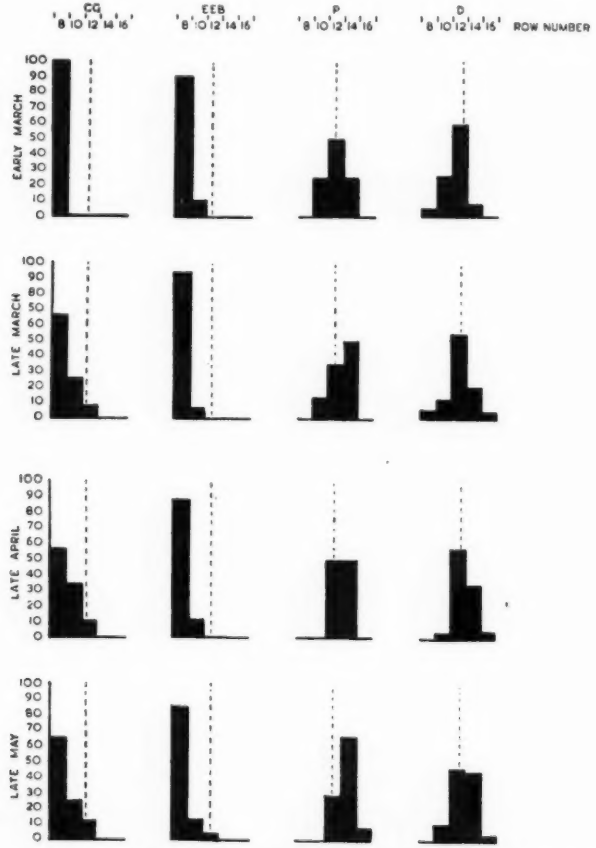

FIG. 7. Histograms showing the effect of sowing time on percentage frequency of row numbers in ears of four sweet corn varieties. Rows show distributions of four varieties for each sowing date. Columns indicate distributions of each variety for four sowing dates.

Sowing sweet corn extra early in England does not produce the desired early harvesting; sowings should not be made before the end of March.

(ii) *Ear characters and yield.*—Marketable ears were measured when picked. Length was not materially affected except in Early White Market which had somewhat longer ears from later sowings (Fig. 6).

Similarly, ear-width was not influenced by sowing time. Ear-weight, however, very slightly increased for later sowings of Early White Market and Canada Gold. Ears of different varieties have characteristic row numbers. Fig. 7 shows frequency distributions of this character for four varieties according to sowing date. The proportion of ears with higher row number clearly increased with later sowings. This is in keeping with other effects of sowing time on plant-growth. In general, sowing date does not affect the economic value of sweet-corn ears.

The number of marketable ears from main shoots tended to fall off for May 24 sowings (Fig. 8). This is very marked in a late variety like Plumptip. On the whole, earlier sowings gave slightly higher individual plant-yields. In America, ears for market are picked from main stems, most varieties producing only one or two good ears rather than a large number of second-grade ears. In this country some varieties like Dependogold and Plumptip also have marketable ears on their tillers which are somewhat later than main ears, but they are economically important in England.

Estimated yields of marketable ears per acre are given in Table 1. Early March sowings gave very poor yields; the highest were from March 28 and April 26. Yields of May 24 sowings showed a falling off; this is more marked for late varieties such as Plumptip. It was mostly ascribable to reduced germination in May [1].

To get early, high-yielding crops of sweet corn in England sowings should be made during the early part of April.

TABLE 1

Yield of Marketable Ears per Acre (in thousand lb.)

*Variety**	*Date sown*			
	March 1	*March 22*	*April 26*	*May 24*
D . . .	182·0	302·5	276·6	230·8
EEB . .	54·4	229·0	192·3	205·8
CG . .	53·1	183·8	143·8	104·1
P . . .	39·5	301·3	280·4	155·7
GS . .	9·8	104·1	136·3	78·4
EWM . .	0·0	109·8	138·2	101·6
Mean . .	56·5	205·1	194·6	146·1

* Key to varieties as in Fig. 1.

(iii) *Plant height and tiller number.*—Plants from later sowings tended to be taller than those sown earlier, and these differences were significant (Fig. 9). Sowing time may thus be of some importance in England, where maize is grown for silage. Fig. 10 shows that, in general, tiller number decreased the later varieties were sown. These values were not significant, although varieties significantly differed in their tillers. Values of (mean plant height × mean tiller number) were remarkably constant in each variety for different sowings. Day-length and other factors

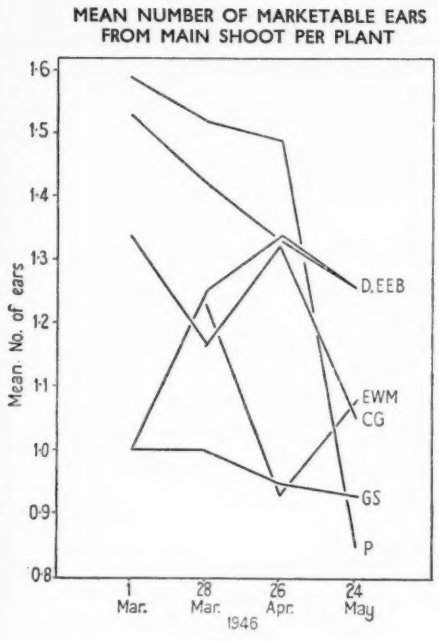

FIG. 8

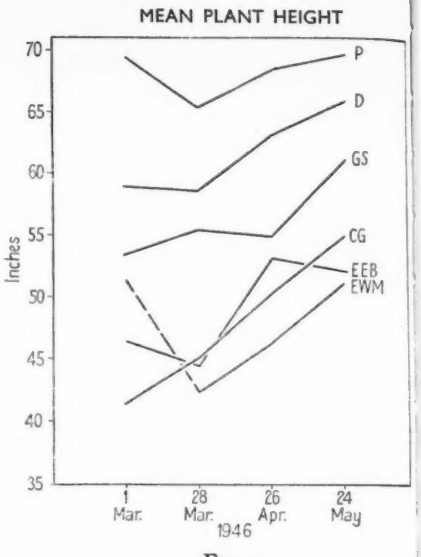

FIG. 9

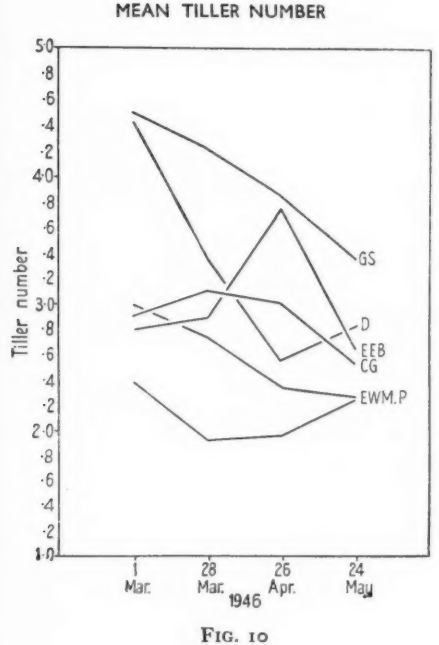

FIG. 10

FIG. 8. Effect of sowing time on plant yield of six varieties of sweet corn. Mean number of marketable ears per plant from main stems plotted against sowing date.

Key to Varieties. As for Fig. 1.

FIG. 9. Effect of sowing time on plant height of six sweet corn varieties. Mean plant height (in inches) plotted against sowing date.

Key to Varieties. As for Fig. 1.

FIG. 10. Effect of sowing time on tiller production of six sweet corn varieties. Mean tiller number per plant plotted against sowing date.

Key to Varieties. As for Fig. 1.

therefore determine whether growth is by elongation of main stem or by tiller production.

Summary

Six varieties of sweet corn were sown at 28-day intervals from March 1, 1946. Although both March sowings flowered simultaneously, in general the later plants were sown, the shorter was the interval to flowering. Maturity was directly proportional to flowering time; hence this character gives good indication of harvesting date. Protandry and ear characters, e.g. length, width, and weight, were not materially affected by sowing date. Later sowings gave more ears with higher row number. Plant yield was slightly higher for earlier sowings; sweet corn should thus be sown in early April in England. Plants from earlier sowings were shorter and had more tillers.

Acknowledgement.—The writer thanks Professor K. Mather for suggesting this investigation, which was carried out during the tenure of a graduate grant from the Agricultural Research Council.

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PRODUCTION FROM GRASSLAND IN SOUTH AFRICA

[FERTILIZER TREATMENTS AND LIVESTOCK GAINS ON VELD]

T. D. HALL, D. MEREDITH, AND R. E. ALTONA

(*Agricultural Advisory Section, African Explosives and Chemical Industries, Ltd., Johannesburg, South Africa*)

WITH PLATES 1, 2, 3

FERTILIZER experiments on natural veld or pastures have been carried out for some years at 'Frankenwald', the Botanical Research Station of the University of the Witwatersrand, by the Agricultural Advisory Section of African Explosives and Chemical Industries, Ltd. These experiments have been described in detail by Hall et al. [1] and by Meredith [2], and thus a brief description of the area will suffice here. Frankenwald lies at an altitude of about 5,500 ft. between Johannesburg and Pretoria. The area is considered agriculturally poor, having sandy soils of granitic origin deficient in the three major plant-food elements, and a pH ranging from 4·5 to 6·0 under natural conditions. The average seasonal rainfall over 14 seasons is 31·11 in., most of which falls in the summer growing-season from November to March.

The original grass cover consisted mainly of *Tristachya hispida*, *Trachypogon plumosus*, *Elyonurus argenteus*, *Eragrostis chalcantha*, *Digitaria tricholaenoides*, and *Heteropogon contortus* as the dominant species, with *Brachiaria serrata*, *Harpechloa falx*, *Microchloa caffra*, *Themeda triandra*, and several others as species of lesser importance. This veld type is a high stage in the grass succession and is probably the stage preceding a mixed scrub climax, consisting of several of the above grasses along with species of Acacia, Royena, Rhus, Gymnosporia, and some others.

In 1933 when the experiments were first started 10 permanent square-metre quadrats were located in each two-morgen[1] camp of the experiment dealt with in this paper. The average of all the quadrats in 10 camps gave the following percentage composition and basal cover:

Tristachya hispida	1·45
Trachypogon plumosus	1·54
Elyonurus argenteus	2·37
Eragrostis chalcantha	2·39
Digitaria tricholaenoides	2·08
Heteropogon contortus	2·51
Brachiaria serrata	0·71
Harpechloa falx	0·62
Microchloa caffra	0·30
Themeda triandra	0·26
Other grasses	3·61
Sedges, other non-grass plants and weeds	0·68
Total basal plant-cover	18·52 per cent.

[1] 1 morgen = 10,244 sq. yds. (Eng.) = 2·116 acres.

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The experiment has been modified since it was first laid down in 1933 and the location of some of the permanent quadrats has been lost. In place of the original two-morgen camps the treatments are based on 4 one-morgen camps and reliance is now placed on the point-quadrat method of determining botanical composition. The following table shows the average botanical composition of the treatments during the 1948–9 season:

TABLE 1. *Average Composition of Veld Herbage in 1948–9*

Grasses	*Treatment*				
	O	P	NP	NPK	N_3PK
Tristachya hispida	4·2	4·6	7·1	2·2	1·4
Trachypogon plumosus	4·4	2·8	2·4	2·9	0·6
Elyonurus argenteus	4·0	2·4	0·8	0·8	..
Eragrostis chalcantha and *E. capensis*	8·1	4·0	0·9	1·5	..
Digitaria tricholaenoides	1·1	1·1	3·3	2·3	1·9
Heteropogon contortus	1·4	5·0	3·0	5·3	..
Brachiaria serrata	..	..	0·6	..	..
Harpechloa falx	0·9	0·7	1·3	1·2	2·9
Digitaria monodactyla	..	..	0·5	..	..
Themeda triandra	..	..	0·8	1·5	..
Eragrostis spp.	..	..	3·4	6·4	17·7
Cynodon dactylon	..	..	1·5	..	5·5
Cymbopogon excavatus	0·8	..	..	..	0·9
Aristida spp.	0·9	..	..	0·7	..
Other grasses	4·7	6·6	4·3	4·9	5·2
Non-grasses	0·8	0·5	0·5	0·9	0·9
Total basal cover	31·3	27·7	30·4	30·6	37·0

In the 1938–9 season it was decided to include in the experiment an N_3PK treatment on a *Paspalum dilatatum–Chloris gayana* (Rhodes grass) mixture and 5 years' results are available. During the 1945–6 and 1946–7 seasons no grazing took place in this treatment as the camps were ploughed and re-seeded.

A further N_3PK treatment was started in the 1947–8 season on what is termed locally 'old fallows'. The four-morgen in this treatment had been old native lands and when the experiment started had an average basal cover according to the point-quadrat method of 3·25 per cent. *Cynodon dactylon* and 6·4 per cent. other grasses and weeds, mostly Eragrostis and Sporobolus spp. By the end of the 1947–8 season the cover in this treatment had improved considerably and was, in percentages, Eragrostis spp. 9·1, *Cynodon dactylon* 5·8, *Eleusine indica* 1·3, *Paspalum dilatatum* 0·5, other grasses 3·8, non-grasses and sedges 4·8, giving a total basal cover of 25·3 per cent.

Grazing methods.—In this experiment, as it was modified in the 1937–8 season, beef steers have been used as the grazing animals. Uniform animals weighing 700 to 900 lb. were purchased usually for each season, though on two occasions animals were used for 2 seasons. The steers were divided into groups and each group remained for the summer

grazing-season on the 4 camps of the respective fertilizer treatments, which were grazed in rotation. The steers were weighed at the beginning of the season and thereafter at regular intervals until the end of the grazing-season. For the first 4 years weighing was done at fortnightly intervals and at 28-day intervals in the last 4 seasons. All weights were taken on 3 consecutive days at the same time and the averages were used.

Throughout this experiment no supplementary feeds were given to the animals during the summer grazing-season. The live-weight gains recorded, therefore, have been made entirely on the veld grazing. The usual procedure was to take the animals out of the camps between 9 and 10 a.m. each day for water. After watering the steers were put in a shade camp containing little or no grass, where they remained until after 3 p.m. They were then taken to water again and then put back in the camps. Grazing thus took place from 4 p.m. until 9 a.m.

The figures quoted are for 8 seasons from 1937–8 to 1948–9. There was a break of 4 seasons from 1941–2 to 1944–5 owing to staff difficulties and fertilizer shortages due to war conditions. During this period all camps were cut for hay. The results obtained have been given fully elsewhere [3, 2].

Fertilizer treatments compared.—The treatments compared have been O, P, NP, NPK, and N_3PK, where P = 400 lb. rock and superphosphate mixture per morgen once annually: N = 200 lb. sulphate of ammonia (21·0 per cent. N) once annually in spring; N_3 = 600 lb. sulphate of ammonia per morgen in three 200-lb. dressings during the season; and K = 80 lb. KCl per morgen once annually.

Prior to the outbreak of the war the rock phosphate and superphosphate mixture used in the P treatments contained 10 per cent. water-soluble, 17 per cent. citric-soluble, and 24 per cent. total P_2O_5. During the war, however, phosphates were difficult to obtain and the grades were changed and in the 1940–1 season no phosphates were applied. No potash was applied in the K treatments in this season.

Sulphate of ammonia was also unobtainable in some years and ammonium nitrate or nitrate of soda was used. On one occasion extra nitrogen was given to the N treatments and in one season when ammonium nitrate was used, the amount of nitrogen applied was increased above that contained in 200 or 600 lb. sulphate of ammonia. The average amounts of plant-food given per morgen over the 8 years were as follows:

TABLE 2. *Average Plant-food Applications*

Treatments	*Lb. per morgen—8-year averages*		
	N	P_2O_5	K_2O
P	..	65·6	..
NP	50·7	65·6	..
NPK	50·1	63·9	31
N_3PK—veld	133·5	63·9	31
N_3PK—Rhodes and Paspalum (5 years)	127·3	61·2	16
N_3PK—Old fallows (2 years)	122·9	50·4	..

All applications of fertilizer were broadcast over the pastures either by hand or machine when weather conditions were favourable. Nitrogenous fertilizers were usually applied after rains of ½ in. or more. No cultivation of the pastures took place.

Rates of stocking.—Based on the results obtained in this experiment before the 1937–8 season, it was decided to put 3 steers each in the O and P treatments, 4 each in the NP and NPK treatments, and 6 in the N_3PK treatment. These rates of stocking were adhered to throughout the experiment with a few exceptions. Thus in the 1938–9 season 7 animals were placed in the N_3PK–veld treatment, and 9 in the N_3PK–Rhodes and Paspalum treatment, which was started in that season. Nine animals proved to be too many, however, and in subsequent seasons only 6 were placed in this treatment. In the 1939–40 season 4 animals each were put in the O and P treatments and 5 each in the NP and NPK treatments. In the following season the O and P treatments were reduced to 3 steers each, but 5 remained in the NP and NPK treatments. In the last 4 seasons the rate of stocking remained the same, namely, 3 each in O and P, 4 each in NP and NPK, and 6 each in the N_3PK treatments.

Live-weight gains.—Group gains over the 4 seasons and the 8-year average group-gains are given in Table 3.

TABLE 3. *Group Live-weight Gains on Veld in lb. per 4-Morgen*

Treatments	*1937–8*	*1938–9*	*1939–40*	*1940–1*	*1945–6*	*1946–7*	*1947–8*	*1948–9*	*Average*
O . .	489	562	311	724	380	464	514	528	497
P . .	615	598	253	699	380	570	587	513	527
NP . .	914	1,064	908	1,228	646	855	1,394	1,071	1,010
NPK .	841	1,050	736	1,283	706	859	1,379	1,034	986
N_3PK–veld	1,706	1,819	1,479	1,696	1,630	1,422	2,396	1,500	1,706
N_3PK–R and P .	..	1,968	1,135	1,592	..	..	2,545	1,438	1,736
N_3PK–O. F.	..	..	..	..	..	..	1,929	1,381	1,655
Seasonal rainfall .	26·05	28·76	32·25	35·80	25·21	24·49	32·42	19·45	..

R and P signifies Rhodes and Paspalum, O.F., Old fallows

The average live-weight gains per morgen are O = 124, P = 132, NP = 253, NPK = 247, N_3PK–veld = 427, N_3PK–Rhodes and Paspalum = 434, and N_3PK–Old fallows = 414. The average gain of the N_3PK–veld treatment for the same 5 seasons as the N_3PK–Rhodes and Paspalum treatment was grazed is 445 lb.

Statistical analysis of results.—The above results were statistically examined, using 'Students' method. From this statistical analysis it was clear that the differences between the O and P, NP and NPK, and N_3PK–veld and N_3PK–Rhodes and Paspalum treatments, are not significant. As the N_3PK–Old fallows treatment was included for 2 seasons only this treatment was not included in the analysis. On the other hand, the differences between the O and NP, O and NPK, O and N_3PK–veld, and O and N_3PK–R and P are highly significant. Similarly, the differences between the P treatment and the same 4 treatments—NP, NPK, N_3PK–veld, and N_3PK–R and P are also highly significant.

Finally, the differences between the NP and N_3PK–veld treatments and NP and N_3PK–R and P treatments are highly significant. Also the differences between the NPK treatment and the N_3PK treatments on both veld and Rhodes and Paspalum are highly significant.

Other methods of presenting yields.—In addition to the effects of fertilizer treatments on group-gains per unit area, the treatment also affected daily gains per head, as shown in Table 4.

The average annual production of total digestible nutrients is also shown in Table 4, along with the tons live-weight maintained per morgen. The method of arriving at the production of T.D.N. is given by Nevens as follows:

T.D.N. per morgen

$$= 3{\cdot}53 \times \text{live-weight gained p/m} + \frac{\text{live-weight maintained p/m} \times 7{\cdot}76}{1000}$$

The live-weight maintained per morgen, as outlined by Nevens [4] and the Joint Committee Preliminary Report on Pasture Investigations Technique [5] is arrived at from the formula:

$$\frac{\text{Average weight} \times \text{grazing days}}{\text{No. of morgen}}$$

TABLE 4. *Average Daily Gains and Yields of T.D.N.*

Treatment	*Daily gain per head lb.*	*T.D.N. lb. per morgen*	*Live-weight maintained per morgen tons*
O	1·10	1,215	49·3
P	1·17	1,261	49·3
NP	1·59	2,039	72·7
NPK	1·56	2,064	75·7
N_3PK–veld	1·86	3,197	108·4
N_3PK–R and P	1·86*	3,417*	114·3*
N_3PK–O.F.	1·95†	3,016†	100·4†

* 5-year average. † 2-year average.

Economic returns.—From the inception of these experiments it has been realized that they have been of a fact-finding nature and that it would first of all be necessary to determine the nature of the responses to fertilizer treatments before generalizations could be made and recommendations given to farmers. It is also necessary to point out that owing to the organization of the controlled meat trade in South Africa and the fact that these are summer grazing experiments only, steers were always bought at the period of highest prices, namely, October and November, and sold at periods of lowest prices—May and June. Thus in the case of the Super A, Super, Prime A, and Prime grades in the 1949–50 season the price rises by 14*s.* per 100 lb. dressed weight from the end of May to the end of October. Grade 1 prices also increase by 14*s.*, Grade 2 by 13*s.*, Grade 3 by 12*s.*, and Grade 4 by 10*s.* per 100 lb. over the same period.

Steers have also been bought on a basis of animals fit for slaughter and not as feeders, which has also made it difficult to show economic returns.

In the first four seasons quoted, therefore, no steers were sold straight off the veld, as an attempt was made to hold them until the period of highest prices and if possible to fatten them. It was hoped that in this way it could be demonstrated that fertilized veld could be used efficiently in the production of high-quality beef. In the early war years steers were also fattened to provide high-quality carcasses for export. As our main object, however, was to obtain exact data on the capabilities of fertilized veld for beef production, and not to speculate, we decided, after the war, to approach the matter of returns from a different aspect. It was decided that all steers would be sold on the same day and that financial returns per unit area could then be compared. The cost of fertilizers would then be set against the returns from treatments, after the amount obtained on the no-fertilizer treatment had been subtracted. When this is done the returns that may be expected from applications of fertilizers may be gauged or calculated, and any extra profit that may be obtained by the farmer or grazier who will either produce or buy animals, will depend on his efficiency as a producer, or his shrewdness as a speculator.

The steers obtained in December 1945, which grazed in the experiments for two seasons, were therefore sold in one batch in April 1947. A direct comparison of financial returns straight off the veld is thus possible and the results obtained are shown in Table 5:

TABLE 5. *Financial Returns from Steers sold in April 1947*

Treatment	*No. of steers in treatment*	*Average dressed weight lb.*	*Average dressing out %*	*Return per treatment*	*Return per morgen*	*Increase per morgen due to treatment*
				£ s. d.	£ s. d.	£ s. d.
O	3	558	51	51 5 1	12 16 3	..
P	3	589	53	56 3 2	14 0 10	1 4 7
NP	4	621	54	76 3 2	19 0 10	6 0 7
NPK	4	645	55	83 16 7	20 19 2	8 2 11
N_3PK–veld	6	695	54	134 0 5	33 10 1	20 13 10

This Table shows that all treatments showed a profit per morgen as compared with the no-fertilizer treatment. In the NP treatment, N brought about an increase of £5 per morgen, and the NPK compared with NP showed an increase of £1. 18*s*. 4*d*. due to K. When the N_3PK treatment is compared with NPK, the difference brought about by N_2 or an extra 83·4 lb. N per morgen is £12. 10*s*. 11*d*. per morgen.

It should be mentioned that in these animals, which received no supplementary feeding whatsoever, the N_3PK group produced 1 super prime and 5 prime carcasses, NPK 1 super prime and 3 prime carcasses, NP 3 prime and 1 grade I carcasses, P 3 prime carcasses, and O 2 prime and 1 grade I carcasses.

In the following season only 10 animals were sold straight off the veld, as some were needed for other experiments. Of these, 3 prime and 2 grade I carcasses came from the N_3PK–veld treatment; 1 super prime, 1 prime and 1 grade I carcasses from N_3PK–Rhodes and Paspalum; 1 grade II carcass from NPK, and 1 super prime carcass from NP. It will be noted that in this season animals were more variable and no strict comparison between treatments is possible.

Results in the 1948–9 Season

In this season all animals were again sold on the same day, but owing to a glutted market had to be held for a month after the grazing season had ended. During this period they were fed veld hay and a minimum of cowpea hay just to maintain weights. As very slight gains were made, and in some cases slight losses, it is felt that the figures may be used to indicate gains off the veld, and the returns may justifiably be compared with those of the 1946–7 season, already quoted in Table 5.

TABLE 6. *Financial Returns from Steers sold in June 1949*

Treatment	*No. of steers in treatment*	*Average dressed weight lb.*	*Average dressing out %*	*Return per treatment*	*Return per morgen*	*Increases per morgen due to treatment*
				£ s. d.	£ s. d.	£ s. d.
O . .	3	516	52·4	51 12 8	12 18 2	..
P . .	3	515	51·2	48 15 8	12 3 11	−0 14 3
NP .	4	587	53·7	84 15 9	21 3 11	8 5 9 (over O)
NPK .	4	568	53·5	77 18 4	19 9 7	6 11 5 ,,
N_3PK–veld .	6	574	54·2	114 9 7	28 12 5	15 14 3 ,,
N_3PK–R and P .	6*	570	53·0	94 13 3	23 13 4	10 15 2 ,,
N_3PK–O.F. .	6*	542	53·4	88 16 1	22 4 0	9 6 10 ,,

* Only five animals were sold in each of these two groups, one having died in one treatment and the other having sustained a cracked pelvis.

If these two sets of returns are compared it will be noted there is a measure of agreement and if the fertilizer costs per morgen are subtracted, it can be shown that nitrogen shows a return over and above the cost of fertilizer per morgen.

It should be noted that in the case of the 1948–9 steers, the O treatment produced 1 prime A, 1 grade I and 1 grade II carcasses; P treatment 2 grade I and 1 grade II carcasses; NP treatment 3 prime B and 1 grade I carcasses; NPK 1 prime B and 3 grade I carcasses; N_3PK–veld 1 prime B, 4 grade I, and 1 grade II carcasses; and the N_3PK–R and P 1 prime A, 3 grade I, and 1 grade II carcasses; N_3PK–Old fallows 2 prime B, 1 grade I, and 2 grade II carcasses [Plates 1, 2, 3].

These grades emphasize how difficult it is to obtain steers of a uniform nature for experimental purposes and furthermore how difficult it is to

select steers at the beginning of an experiment on the basis of ultimate grade and quality.

TABLE 7. *Financial Returns per Morgen*

Treatment	Season 1946–7			Season 1948–9		
	Increase per morgen due to treatment	*Cost of fertilizer**	*Balance as profit per morgen*	*Increase per morgen due to treatment*	*Cost of fertilizer**	*Balance as profit per morgen*
	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.
P . .	1 4 7	1 6 0	−0 1 5	−0 14 3	1 6 0	−2 0 3
NP . .	6 4 7	3 16 0	2 8 7	8 5 9	3 16 0	4 9 9
NPK .	8 2 11	4 8 0	3 14 11	6 11 5	4 8 0	2 3 5
N_3PK–veld	20 13 10	9 8 0	11 5 10	15 14 3	9 8 0	6 6 3
N_3PK–R and P . .	..	..	..	10 15 2	9 8 0	1 7 2
N_3PK–O.F.	..	..	..	9 6 10	9 8 0	−0 1 2

* Fertilizer costs in both cases derived from rock phosphate and superphosphate at £6. 10s. per ton: sulphate of ammonia £25 per ton, and potassium chloride £15 per ton.

Discussion

The 8-year average results confirm the results published earlier and in some respects provide more definite data than had been obtained previously. Thus with regard to botanical composition of the sward, figures for the 1948–9 season show conclusively that the coarser Eragrostis species have increased in all treatments receiving nitrogen and most markedly in the N_3PK treatments, thus giving precise information about what was previously observation only. These Eragrostis species, mainly *E. curvula*, *E. nebulosa*, and *E. chloromelas*, have a tufted nature and appear to be coarse, but they are well grazed in the fertilized camps and have maintained the weight-increases previously given by the grasses they have superseded. It will be noted also that the percentage grass-cover has increased in all treatments, even O, which is due probably to the management, and most of all in the N_3PK treatment.

The experiment shows in a striking manner that the main fertilizer requirement of this type of grassveld is nitrogen, and that little response is obtained from phosphatic dressings by themselves. Thus if the figures of Table 2 are compared with those of Table 3, it is clear that an average annual application of 65·6 lb. P_2O_5 per morgen results in an increase of only 8 lb. live-weight increase, or in other words, to produce 1 lb. of gain in steers requires 8·2 lb. P_2O_5. The difference between this result and those obtained in the humid areas of North America, Europe, and New Zealand may be ascribed to the almost complete lack of edible legumes in Frankenwald veld. On this type of grassveld, phosphate doubles the P_2O_5-content of the grass, but gives no increase in bulk.

The marked response to nitrogen is shown in both the N and N_3 treatments. In the NP treatment, N in the presence of P has given an increase of 121 lb. live-weight increase per morgen or 2·38 lb. live-

weight gain per lb. of nitrogen applied. The effect of nitrogen alone, in the absence of phosphate, cannot be studied in this experiment, but it is thought that the return would not be as high as 2·38 lb. per lb. of N.

Potash in the presence of phosphate and nitrogen, as an average of 8 seasons, has given no significant increase in live-weight gains.

The extra dressings of nitrogen in the presence of P and K have given a further marked increase, and the difference between the NPK (or the NP) and N_3PK treatments may fairly be ascribed to the N_2 application. Thus an extra application of 83·4 lb. N has given a live-weight increase of 180 lb. per morgen, or 2·16 lb. gain per pound of N.

From this it would appear that the upper limit of nitrogen applications is above 600 lb. sulphate of ammonia per morgen, or its equivalent, as the response to the heavier dressings is of the same order of magnitude as that to the single dressing of 200 lb. sulphate of ammonia.

The foregoing remarks appear to apply equally well to the heavy fertilizer treatments on sown or planted pastures, as shown by the results obtained on a Rhodes grass—*Chloris gayana* and *Paspalum dilatatum* mixture. Incidentally, the grass-cover in this mixture has contained up to 1 or 2 per cent. of lucerne, *Medicago sativa*, which was originally included in the seeds-mixture at the rate of 10 lb. per morgen. It has persisted in the sward, but does not appear to have affected the results to a marked degree.

Perhaps the most encouraging results have been obtained on the N_3PK treatment on the 'old fallows', in view of the poor grass-cover in these camps at the beginning of the 1947–8 season. It is hoped that this treatment may be continued for a few years, as there are large areas of overgrazed and eroded veld in South Africa, as well as abandoned arable areas that have been allowed to 'tumble down to grass'. If it can be shown that these areas can produce live-weight gains as indicated in this experiment, the prospect of early rehabilitation becomes most encouraging.

The average daily gains per head show that not only do the fertilizer treatments containing N give higher carrying capacity per unit area, but also increased daily gains per head. It has commonly been observed in these experiments that daily gains have been high on the fertilized plots receiving N right up to the end of the season, whereas farmers on this veld-type complain that it is of little grazing value after the middle of summer.

The yields of total digestible nutrients also confirm the results given by live-weight gains. These average figures show that 1 lb. of P_2O_5 will produce 0·7 lb. T.D.N. on this type of grassveld; 1 lb. of N in the single dressing 15·3 lb., and 1 lb. of N in the extra N dressings 13·6 lb. on the veld. The results for the N_3PK–R and P for 5 years give 16·0 lb. T.D.N. for every pound of N in the extra N dressings, but if the same 5 years are averaged for the veld then the veld has produced 15·4 lb. T.D.N. for every 1 lb. of N applied. According to these calculations 1 lb. of K_2O has produced 0·8 lb. T.D.N.

The results expressed as tons live-weight maintained per morgen

afford further evidence of the importance of N and the relative unimportance of P and K. Again the figures for the veld if averaged for the same 5 seasons as the N_3PK on Rhodes and Paspalum give a value as good as that for the sown pasture, namely, 113·5 tons as compared with 114·3 tons.

In regard to economic returns Table 7 shows definitely that it does not pay to apply phosphate alone on this veld-type. The application of potash gave a return of £1. 6*s.* 4*d.* per morgen in the 1946–7 season and no response in the 1948–9 season, and it may be concluded that potash is not needed yet on this type of soil. Nitrogen has given returns in both seasons despite very high prices for sulphate of ammonia, and it may reasonably be concluded that with cheaper nitrogenous fertilizers and prices for steers or feeders more in keeping with age, weight, and grade, there is a most promising future for the use of nitrogen on veld in livestock maintenance and production.

Finally, it is noteworthy that the N_3PK on Rhodes and Paspalum showed a small profit despite the loss of one steer, and this treatment on 'old fallows' a small loss, due to the same cause. Had it not been for these losses, the returns would in all probability have been similar to those obtained in the N_3PK–veld treatment.

Summary

The results obtained in a fertilizer experiment on natural veld over 8 seasons are given in this paper. Beef steers were used as grazing animals and results are quoted as live-weight gains per morgen. From these weights the average daily gains per head, the yields of total digestible nutrients, and the tons live-weight maintained per morgen have been calculated.

Botanical analyses have shown that the percentage basal cover has increased in all treatments, and most of all in the treatment receiving the most nitrogen (N_3PK).

The application of nitrogen as sulphate of ammonia has brought about an increase in Eragrostis species in the sward. Again, this has been most marked in the N_3PK treatment.

As an average of 8 seasons, animals on veld without fertilizer made an annual gain of 124 lb. live-weight per morgen in the summer grazing-season.

The application of 400 lb. phosphatic fertilizer per morgen (65·6 lb. P_2O_5 per morgen as an 8-year average) gave no significant increase in live-weight gain.

Nitrogen as sulphate of ammonia at the rate of 200 lb. per morgen, with phosphate, increased the average live-weight gain to 253 lb., and the same amount of nitrogen with phosphate and potash at the rate of 80 lb. KCl per morgen gave 247 lb. live-weight gain.

When nitrogen was applied at the rate of 600 lb. sulphate of ammonia per morgen in 3 dressings (N_3PK) along with phosphate and potash, the annual live-weight gain was increased to 427 lb. per morgen. The same treatment over 5 years on a Rhodes grass and *Paspalum dilatatum* pasture gave 434 lb. per morgen.

All nitrogen treatments increased the daily live-weight gain per head. Phosphate showed a slight increase which is not significant, and potash a slight depressing effect, which is also not significant.

It is thus clear that nitrogen treatments, besides giving increased carrying capacity, brought about increased daily gains as well.

All treatments gave increased yields of total digestible nutrients, but only those due to nitrogen are of statistical significance. It appears that 1 lb. of nitrogen on the veld in the single application (N = 200 lb. sulphate of ammonia per morgen) gave 15·3 lb. T.D.N., and the extra nitrogen in the N_3PK treatment (600 lb. sulphate of ammonia per morgen) 13·6 lb. T.D.N.

On two occasions all steers were sold on the same day at the end of the grazing-season. The financial returns, when worked out per morgen, showed increased returns for treatments including nitrogen over and above the cost of fertilizer per morgen when compared with the returns obtained on the no-fertilizer treatment.

It is concluded that the use of nitrogen on veld shows great promise in giving increased production on a profitable basis.

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The 'N_3PK–Old Fallows' group in April of the 1948–9 season. This group gave two grade prime B, one grade I, and two grade II carcasses

The 'N_3PK–Rhodes and Paspalum' group in April of the 1948–9 season. This group gave one grade prime A, three grade I, and one grade II carcasses

The 'O' group in April of the 1948–9 season. This group produced one grade prime A, one grade I, and one grade II carcasses

The 'P' group in April of the 1948–9 season. This group produced two grade I and one grade II carcasses

The 'NP' group in April of the 1948–9 season. This group gave three grade prime B and one grade I carcasses

The 'NPK' group in April of the 1948–9 season. This group gave one grade prime B and three grade I carcasses

The 'N_3PK–Veld' group in April of the 1948–9 season. This group gave one grade prime B, four grade I, and one grade II carcasses

FIELD EXPERIMENTS IN SELECTIVE WEED CONTROL BY PLANT-GROWTH REGULATORS

I. WEED CONTROL IN CEREAL CROPS

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Introduction.—THE discovery by Slade, Templeman, and Sexton [1, 2] of the selective herbicidal action of plant-growth regulators was the outcome of a series of experiments designed originally to determine whether these substances were in any way responsible for the beneficial properties of organic matter in soils. It was observed at an early stage in the investigation [3, 4] that growth-regulators such as β-indolylacetic acid and α-naphthylacetic acid not only failed to stimulate the growth of plants, measured in terms of dry-matter production, but even had a depressing effect in concentrations above a certain level. This effect was more pronounced with α-naphthylacetic acid than with other compounds studied. Since the degree of rooting in cuttings treated with growth-substances was known to vary greatly from one species to another [5], it was logical to suppose that the higher concentrations of α-naphthylacetic acid might exert a selective influence upon the growth of different plants. This was, in fact, found to be the case [6]. Seed-bed applications of α-naphthylacetic acid at the rate of 25 lb. per acre to oats and yellow charlock (*Sinapis arvensis*) sown on August 23, 1940, in boxes of soil out of doors markedly reduced the germination of charlock without reducing that of oats. Similar applications at the seedling stage killed charlock, mangolds, and sugar-beet, but not oats. Subsequent tests showed that many substituted naphthoxyacetic and phenoxyacetic acids could also inhibit plant-growth, and that greater plantain (*Plantago major*) and yarrow (*Achillea Millefolium*) reacted like yellow charlock; other cereals (rye, barley, and wheat) were resistant in the same way as oats. By November 1941 it was clear that 4-chloro-2-methylphenoxyacetic acid, later known as M.C.P.A. or 'Methoxone', was one of the most active of the compounds tested, and that it readily depressed the germination and early seedling growth of corn buttercup (*Ranunculus arvensis*), fat hen (*Chenopodium album*), corn marigold (*Chrysanthemum segetum*), corn spurrey (*Spergula arvensis*), and field poppy (*Papaver Rhoeas*) at concentrations which were without effect on cereals. Pot and field experiments showed that germination of yellow charlock was suppressed and plants at any stage from seedling to flowering were readily killed by spraying with solutions of sodium 4-chloro-2-methyl phenoxyacetate at rates equivalent to approximately 1 lb. acid per acre. Other compounds which showed marked activity included 2,4-dichlorophenoxyacetic acid, later known as D.C.P.A., 'Chloroxone', or 2,4-D, and the sodium salt and esters of β-naphthoxyacetic acid. These results were communicated to the Secretary of the Agricultural Research Council in November 1942.

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In 1942 Zimmerman and Hitchcock of the Boyce-Thompson Institute [7] reported the outstanding activity of 2,4-dichlorophenoxyacetic acid and its derivatives as growth-regulators for inducing parthenocarpy and cell-elongation in tomato plants, but the lower susceptibility of cereal seeds and seedlings to these substances was not noted. In the same year Nutman, Thornton, and Quastel at Rothamsted [8] observed that 2,4-dichlorophenoxyacetic acid was highly toxic to red clover and that the toxicity was retained to a satisfactory extent in unsterilized soil, whereas that of α-naphthylacetic acid and other compounds tested was rapidly lost. It was later shown that on Woburn soil, a light sand low in organic matter, clover and especially sugar-beet were highly susceptible to 2,4-dichlorophenoxyacetic acid in concentrations as low as 1 part per million, whilst wheat was also affected at 10 parts per million.

The field experiments forming the subject of the present paper were begun at Jealott's Hill in 1943. A preliminary account of selective weed-control experiments in cereals carried out in 1943, 1944, and 1945 appeared in the *Journal of the Ministry of Agriculture*, June 1946 [9], but the full results have not previously been published. These include a study[1] of the effect of M.C.P.A. on both weedy and weed-free cereal crops. Work since 1945 has been devoted mainly to the control of weeds in grassland,[2] with particular attention to the eradication of buttercups, ragwort, creeping thistle, and other persistent weeds. In addition, numerous weed-control experiments in overseas countries have been instigated in conjunction with subsidiary and associated companies of Imperial Chemical Industries Ltd. and with the Dominion and Colonial Departments of Agriculture. These will be described elsewhere.

Comparative trials of M.C.P.A. with other selective weedkillers were conducted from 1943 onwards under the auspices of the Agricultural Research Council by G. E. Blackman [10], who found that yellow and white charlock, corn buttercup, pennycress (*Thlaspi arvense*), treacle mustard (*Erysimum cheiranthoides*), cornflower (*Centaurea Cyanus*), Venus' comb (*Scandix Pecten-Veneris*), hemp nettle (*Galeopsis Tetrahit*), and ivy-leaved speedwell (*Veronica hederefolia*) were all readily killed and germination inhibited by M.C.P.A. at concentrations which had no adverse effect on spring- or autumn-sown cereals. Of these Venus' comb, corn buttercup, cornflower, and white charlock were much more susceptible to M.C.P.A. than to D.N.O.C. (ammonium dinitro-*ortho*-cresylate), copper chloride, or sulphuric acid. Similar results were obtained with D.C.P.A. [11]. Amongst the annual weeds reported as largely resistant to M.C.P.A. and D.C.P.A. were scentless mayweed (*Matricaria inodora*), chamomile (*Matricaria Chamomilla*), corn marigold, willow weed (*Polygonum Persicaria*), knotgrass (*Polygonum aviculare*), cleavers (*Galium Aparine*), chickweed (*Stellaria media*), parsley piert (*Alchemilla arvensis*), and fumitory (*Fumaria officinalis*). Certain other weeds, such as fat hen, field poppy, spurrey, ivy-leaved speedwell, hemp nettle, and bearbind (*Polygonum Convolvulus*), appeared to be susceptible only in the early stages of growth [12]. Later work by Blackman and Holly [13] has shown that M.C.P.A. may safely be used

[1] Part II of the present paper. [2] Parts III and IV of the present paper.

for selective weed-control not only in wheat, oats, and barley, but also in linseed (at rates not exceeding 2 lb. per acre) and in flax (at rates not exceeding ¾ lb. per acre). The latter rate may be expected to give at least 80 per cent. 'kill' of yellow charlock, pennycress, treacle mustard, and shepherd's purse (*Capsella Bursa-pastoris*).

Field trials in 1945 by the Norfolk War Agricultural Executive Committee [14], embracing nearly 1,600 acres of wheat, oats, and barley, showed excellent results with 1 lb. M.C.P.A. per acre in 100 gal. spray or 2 lb. M.C.P.A. per acre in 2 cwt. dust on pennycress and white and yellow charlock. The effect on creeping thistle (*Cirsium arvense*), poppy, and bladder campion (*Silene vulgaris*) was variable, whilst docks (*Rumex obtusifolius* and *R. crispus*) suffered severe damage.

Meanwhile, prompted by the (unpublished) suggestion of E. J. Kraus in 1941 that plant-growth regulators might be used as herbicides, similar work was being undertaken independently in the United States by Hamner and Tukey [15], Marth and Mitchell [16], and several others [17]. The American investigations, however, were centred mainly around D.C.P.A. and T.C.P.A. or 2,4,5-T (2,4,5-trichlorophenoxyacetic acid), and little attention was paid to M.C.P.A. Much evidence has since been published upon the action of D.C.P.A. upon the weeds and crops of the U.S.A. and Canada [18, 19, 20] and of Australia [21, 22]. In Europe, extensive trials of both M.C.P.A. and D.C.P.A. have been conducted by H. Osvald [23] in Sweden, A. Hilli [24] in Finland, and others. Further lists of susceptible and resistant weeds have been published by the Ministry of Agriculture [25], Halliday [26], Pearse [27], and Holmes [28].

Experimental Results

Investigations in 1943.—An experiment was conducted at Jealott's Hill on spring-sown oats heavily infested with yellow charlock (*S. arvensis*). Weed-counts on untreated plots showed the infestation to be approximately 12 plants per square foot. Both D.C.P.A. (sodium salt) at 3·25, 6·5, and 9·75 lb. per acre and M.C.P.A. (sodium salt) at 2, 4, and 6 lb. per acre, applied as dusts in 1 cwt. china clay per acre on May 3, when the weeds were at the 4–6 leaf stage, completely eradicated the charlock. D.C.P.A. at 4·3 and 8·4 lb. per acre and M.C.P.A. at 2·6 and 5·2 lb. per acre, applied as dusts in 1 cwt. china clay per acre 9 days later when the weeds were breaking into flower, also gave a complete kill. A similar result was obtained when M.C.P.A. at 2·6 and 5·2 lb. per acre was applied as a spray in 100 gal. of water per acre.

The appearance of the affected plants was extremely interesting. Within 2 or 3 days the leaves began to curl and bend and the stems to twist in a typical epinastic response. The leaves turned first yellow and then red. The stems became very swollen with splits in the epidermis and excresences which seemed to consist of a coalescing mass of numerous root-initials that failed to develop. The leaves and finally the stems then completely died away. On May 27 the charlock on the untreated plots, which was then strong and in full flower, was sprayed with D.C.P.A. at rates of 1·63 and 3·25 lb. per acre or M.C.P.A. at 1·0 and

2·0 lb. per acre. In all cases weed-growth was immediately arrested, no seed was set, and the plants died. There was no damage to the oat crop by any of these treatments as shown by the grain yields of the plots at harvest.

Investigations in 1944.—Experiments were confined to M.C.P.A. (sodium salt) and were designed to discover the optimum time and rate of application for the eradication of yellow and white charlock, by means of dusts and sprays.

Three methods of application were tried. In the first, the active material was diluted with china clay and the mixture applied by hand at 1 cwt. per acre as evenly as possible, using a pot with a perforated lid and a portable screen to prevent the dust drifting. In the second method the active material was granulated with sulphate of ammonia, also applied by hand at the same rate. In the third method the material was applied in aqueous solution at 100 gal. per acre by means of a knapsack sprayer.

The experiments were conducted at various centres in Norfolk, Hants, Berks., and Oxon. in crops of spring barley and spring and winter oats. At each centre there was fourfold replication of all the treatments tested, and the plots were fully randomized. The plots were either 1/100 or 1/200 acre. The effectiveness of the treatments was measured by taking weed-counts within a 1-ft. square quadrat thrown at random ten times on each plot. The results are shown in Table 1.

Investigations in 1945

1. *Fully replicated field experiments.*—The 1945 experiments were designed primarily to extend our knowledge of the effect of M.C.P.A. on weed species other than yellow charlock (*S. arvensis*), white charlock (*Raphanus Raphanistrum*), pennycress (*T. arvense*), and corn buttercup (*R. arvensis*), all of which had been shown to be readily controlled.

Ten cereal sites were chosen, four in an area of fairly high rainfall in south Devon, all in spring-sown corn, and six in a drier area moderately near to Jealott's Hill, two of which were autumn-sown corn and four in spring-sown cereals. Eight of the sites were infested mainly with annual weeds, but in the other two the main weed was an important perennial (creeping thistle, *Cirsium arvense* or docks, Rumex spp.). All centres proved to be heavily infested with weeds, although in the spring-sown cereals not always those expected.

M.C.P.A. was applied in sprays or dusts at 0, 1, 2, and 4 lb. per acre to the annual-weed infestations, and at 0, 2, 4, and 8 lb. per acre where perennial weeds predominated. Separate applications were made in early, medium, and late spring. In the spray treatments the material was applied in aqueous solution at 100 gal. per acre by means of an Eclipse knapsack sprayer. The dusts, which were prepared by diluting 'Methoxone' (40 per cent. active principle) in finely ground calcium carbonate, were applied at 2 cwt. per acre, using a portable screen to reduce the risk of drifting. Each experiment contained four replicate plots of 1/200 acre for each treatment.

Results.—When sufficient time had elapsed after the early spring application to allow the weeds to die or show signs of being affected, the

TABLE 1. *Results of 1944 Investigations*

Weed species and centre	*Treatment*		*Weed density on untreated plots (plants per sq. ft.)*	*Percentage 'kill' by M.C.P.A. at different rates (lb. per acre)*			
	Stage of growth	*Type of material*		0·5	1·0	2·0	4·0
Sinapis arvensis (Micheldever, Hants)	Pre-emergence	Dust	15·6	..	78	80	99
	4-leaf	Dust	17·2	60	84	98	..
		Dust + Amm. sulph.	13·1*	5	0	0	..
		Spray	14·8	100	100	100	..
(E. Ilsley, Berks.)	Pre-emergence	Dust	3·2	..	50	88	92
	4-leaf	Dust	20·3	33	47	76	..
		Dust + Amm. sulph.	19·6*	0	0	0	..
		Spray	20·4	85	99	100	..
Raphanus Raphanistrum (Watlington, Oxon.)	Pre-emergence	Dust	65·6	..	89	93	97
	4-leaf	Dust	19·2	21	15	60	..
		Dust + Amm. sulph.	19·9*	3	0	0	..
		Spray	21·5	78	93	98	..
	Flowering	Dust	15·0	..	50	24	30
		Spray	16·1	..	27	87	97
(Shillingford, Oxon.)	Pre-emergence	Dust	34·0	..	76	93	95
		Dust + Amm. sulph.	34·8*	..	21	88	93
	4-leaf	Dust	13·3	..	90	100	100
		Dust + Amm. sulph.	12·0*	..	3	8	63
		Dust	14·3	31	49	85	92
		Dust + Amm. sulph.	16·5*	5	13	28	28
		Spray	18·5	96	100	99	100
Ranunculus arvensis (Jealott's Hill, Berks.)	4-leaf	Dust	14·6	..	35	85	97
		Spray	18·8	..	99	98	100
Thlaspi arvense (Woodbastwick, Norfolk)	4-leaf	Dust	..	..	(85)	(100)	..
		Spray	..	..	(100)	(100)	..

* Weed density on plots which received ammonium sulphate but no M.C.P.A.
Figures in brackets are approximate estimates.

TABLE 2. *Centres for M.C.P.A. Field Experiments, 1945*

Centre no.		*Soil type*	*Soil pH*	*Crop*	*Times of application*		
					1st	*2nd*	*3rd*
1	Woking, Surrey	Very light loam	5·63	Oats and peas	Mar. 15	May 3	May 15
2	Henley, Oxon.	Gravelly loam	6·25	Spring oats	,, 17	,, 4	,, 18
3	Eynsham, Oxon.	Heavy clay loam	6·07	Winter wheat	,, 18	Apr. 27	,, 17
4	E. Ilsley, Berks.	Medium loam with flints	7·45	Spring barley, winter wheat	,, 20	May 8	,, 22
5	Holyport, Berks.	Strong loam	6·20	Winter wheat	,, 22	,, 27	,, 16
6	Kingsbridge, Devon	Medium loam	5·18	Spring oats	,, 27	,, 4	..
7	Kingsbridge, Devon	Light-medium loam	6·3	Spring oats	,, 28	,, 1	June 4
8	Totnes, Devon	Light loam	6·1	Spring oats	,, 28	,, 7	..
9	Kingsbridge, Devon	Medium loam	6·14	Spring barley	,, 29	,, 3	..
10	Holyport, Berks.	Sandy loam	5·44	Spring barley	May 5	,, 29	June 13

effectiveness of the treatments was measured by taking weed-counts within a 1 sq. ft. quadrat thrown at random 10 times on each plot. The crops were then at an early stage of growth, averaging 3–6 in. high.

At the second and third applications, when the crops averaged 12–16 in. and 16–24 in. high, the system of weed-counts per quadrat had to be abandoned. A visual 'points value' system was used instead. Each application was 'walked and scored' by not less than two people and at times three, each man doing his own scoring on a blank layout to avoid bias. At the completion of the observation, notes of values were compared and where large differences for a single plot were recorded the observers returned to the plot for a further scoring. Where differences were small the mean was taken. After a little practice at this method very good agreement of scores was obtained.

The results are summarized in Tables 3, 4, and 5.

TABLE 3. *Percentage 'Kill' of Weed Species by Early Spring (March) Applications of M.C.P.A.*

Weed	Centre no.	Density on untreated plots (plants per sq. ft.)	Weed-size	Percentage 'kill'							
				Spray (lb. per acre)				Dust (lb. per acre)			
				1	2	4	8	1	2	4	8
Anagallis arvensis (Scarlet Pimpernel)	3	2·1	Seedling	65	98	90	..	60	84	77	..
Cerastium vulgatum (Mouse-ear Chick-weed)	1	1·5	Not emerged	..	86	97	100	..	100	100	93
	5	0·5	Seedling	40	85	65	..	70	60	50	..
Chenopodium album (Fat Hen)	2	3·1	Not emerged	69	97	99	..	84	95	100	..
	3	4·9	Seedling	55	67	93	..	68	78	57	..
	9	1·4	Not emerged	96	100	100	..	89	89	100	..
Chrysanthemum segetum (Corn Marigold)	10	12·3	,,	39	59	85	..	47	69	89	..
Cirsium arvense (Creeping Thistle)	1	0·9	,,	..	73	81	97	..	100	100	70?
	7	1·1	,,	51	81	74	..	33	47	74	..
	8	1·1	,,	31	48	60	..	55	71	71	..
	9	2·2	,,	40	53	71	..	45	45	67	..
Fumaria officinalis (Fumitory)	4	8·5	,,	53	55	75	..	23	58	74	..
	8	1·7	,,	21	61	57	..	14	20	61	..
Galium Aparine (Cleavers)	3	6·2	Seedling	0	0	0	..	0	12	0	..
Lathyrus Aphaca (Yellow Vetching)	5	5·6	,,	70	71	80	..	62	45	66	..
Matricaria inodora (Scentless Mayweed)	1	0·9	Not emerged	..	76	100	100	..	80	94	91
	10	1·0	,,	92	100	100	..	97	100	100	..
Papaver Rhoeas (Poppy)	4	8·2	,,	98	98	100	..	84	99	97	..
Polygonum aviculare (Knotgrass)	1	11·9	,,	..	0	84	76	..	55	41	59
	3	3·5	Seedling	54	49	76	..	0	26	33	..
	4	1·8	Not emerged	47	75	95	..	64	72	78	..
	9	0·8	,,	41	72	81	..	47	37	34	..
Polygonum Convolvulus (Black Bindweed)	4	1·6	,,	37	51	74	..	0	17	52	..
	5	1·0	Seedling	39	56	39	..	49	54	71	..
	9	1·5	Not emerged	29	66	75	..	14	31	70	..
Polygonum Persicaria (Persicaria)	1	0·8	,,	..	0	39	58	..	33	52	0
Potentilla Anserina (Silverweed)	6	2·3	,,	..	51	30	?	..	0	56	77
	7	2·5	,,	53	37	56	..	79	69	70	..
Ranunculus spp. (Buttercup)	1	3·2	Not emerged	..	84	98	100	..	96	92	100
	3	16·6	Estab. plants	56	72	93	..	43	69	78	..
	4	1·1	Not emerged	91	95	100	..	63	81	100	..
	5	9·9	Seedlings	78	89	93	..	62	66	87	..
	6	2·1	Not emerged	..	61	56	80	..	40	51	65
	7	1·4	,,	20	31	77	..	57	59	72	..

TABLE 3 (*cont.*)

Weed	Centre no.	Density on untreated plots (plants per sq. ft.)	Weed-size	Percentage 'kill'							
				Spray (lb. per acre)				Dust (lb. per acre)			
				1	2	4	8	1	2	4	8
Rumex Acetosella (Sheep's Sorrel)	2	31·6	3–4 in.	55	74	90	..	46	78	87	..
	6	7·4	Not emerged	..	71	71	83	..	69	82	78
	7	11·6	,,	30	31	41	..	0	34	39	..
	8	18·4	,,	4	37	32	..	0	30	45	..
Rumex obtusifolius (Broad Dock)	6	0·6	,,	..	60	68	64	..	52	56	60
Scleranthus annuus (Knawel)	2	2·7	,,	95	98	100	..	88	97	98	..
Senecio vulgaris (Groundsel)	1	0·6	,,	..	99	100	100	..	100	100	100
Sinapis arvensis (Yellow Charlock)	4	2·3	,,	98	93	100	..	94	95	96	..
	10	2·2	,,	100	100	100	..	100	100	100	..
Spergula arvensis (Spurrey)	1	3·5	,,	..	90	96	96	..	96	99	88
	2	1·8	,,	55	86	97	..	100	88	91	..
	7	4·7	,,	73	90	99	..	66	95	95	..
	8	2·9	,,	83	97	97	..	95	95	94	..
	10	3·5	,,	73	82	97	..	83	88	99	..
Stellaria media (Chickweed)	1	4·9	,,	..	90	93	98	..	79	92	92
	4	4·4	,,	78	89	99	..	61	88	95	..
	10	0·8	,,	87	94	100	..	75	94	100	..
Taraxacum officinale (Dandelion)	6	1·4	,,	..	91	100	100	..	98	98	98
Veronica hederefolia (Speedwell)	4	1·0	,,	52	35	92	..	32	80	85	..
Viola tricolor (Heartsease)	1	3·3	,,	..	69	99	96	..	77	98	77
	2	7·3	,,	35	71	87	..	49	78	78	..
	4	0·6	,,	91	100	100	..	91	100	82	..
	8	5·0	,,	63	88	92	..	54	85	87	..

TABLE 4. *Susceptibility of Weed Species to Medium Spring (early May) Applications of M.C.P.A.*

Weed	Centre no.	Density on untreated plots (plants per sq. ft.)	Weed-size	Degree of susceptibility							
				Spray (lb. per acre)				Dust (lb. per acre)			
				1	2	4	8	1	2	4	8
C. album (Fat Hen)	2	3·1	4–8 in.	SS	SS	SS	..	S	SS	SS	..
	5	1·0	Seedlings	..	SS	SS	SS	..	S	SS	SS
C. segetum (Corn Marigold)	10	12·3	4–6 in.	R	R	R	..	R	R	R	..
C. arvense (Creeping Thistle)	7	1·1	..	S	S	SS	..	s	S	SS	..
	9	2·2	6–8 in.	s	SS	SS	..	s	R	R	..
G. Aparine (Cleavers)	3	6·2	¼–10 in.	R	R	R	..	R	R	R	..
P. Rhoeas (Poppy)	4	1·8	10–14 leaves	s	SS	SS	..	s	SS	SS	..
P. aviculare (Knotgrass)	1	11·9	4–8 in.	..	R	R	R	R	R	R	..
Ranunculus spp. (Buttercup)	3	16·6	Seedling to flowering	s	s	SS	..	R	s	S	..
	5	9·9		R	r	s	..	R	r	s	..
R. Acetosella (Sheep's Sorrel)	5	0·6	Seedlings	..	r	S	S	..	R	r	S
Rumex spp. (Dock)	6	0·6	8 in. diam.	..	r	S	SS	..	s	S	S
	9	..	..	S	S	SS	..	S	S	SS	..
S. annuus (Knawel) } *S. arvensis* (Spurrey) }	2	2·7 1·8	4–6 in.	R	R	S	..	r	R	R	..
V. tricolor (Heartsease)	2	7·3	1–6 in.	R	R	s	..	R	R	R	..

SS = highly susceptible (over 90 per cent. 'kill').
S = susceptible (70–90 per cent. 'kill').
s = moderately susceptible (50–70 per cent. 'kill').
r = moderately resistant (30–50 per cent. 'kill').
R = resistant (under 30 per cent. 'kill').

TABLE 5. *Susceptibility of Weed Species to late Spring (late May) Applications of M.C.P.A.*

Weed	Centre no.	Density on untreated plots (plants per sq. ft.)	Weed-size	Degree of susceptibility: Spring (lb. per acre) 1	2	4	8	Dust (lb. per acre) 1	2	4	8
C. album (Fat Hen)	2	3·1	Seeding 10–15 in.	R	s	SS	..	s	s	S	..
C. segetum (Corn Marigold)	10	12·3	12 in.	R	R	R	..	R	R	R	..
G. Aparine (Cleavers)	3	6·2	½–14 in.	R	R	R	..	R	R	R	..
P. Rhoeas (Poppy)	4	1·8	Flowering	S	SS	SS	..	s	s	SS	..
P. aviculare (Knotgrass)	1	11·9	6–8 in.	..	r	SS	SS	..	R	r	S
	4	0·8	..	s	s	S	..	R	R	R	..
P. Convolvulus (Black Bindweed)	4	0·6	1–8 in.	R	R	R	..	R	R	R	..
Ranunculus spp. (Buttercup)	3	16·6	Flowering	s	s	s	..	r	r	S	..
	5	9·9	1–18 in.	r	s	S	..	r	r	s	..
S. annuus (Knawel) / *S. arvensis* (Spurrey)	2	..	15–16 in. / 6–10 in.	R	r	r	..	r	R	r	..
S. media (Chickweed)	4	1·4	..	R	R	R	..	R	R	R	..
V. tricolor (Heartsease)	2	7·3	Flowering 1–6 in.	R	s	r	..	R	R	R	..

SS = highly susceptible (over 90 per cent. 'kill').
S = susceptible (70–90 per cent. 'kill').
s = moderately susceptible (50–70 per cent. 'kill').
r = moderately resistant (30–50 per cent. 'kill').
R = resistant (under 30 per cent. 'kill').

For both pre-emergence and late applications, spraying gave generally better results than dusting.

There was no apparent relationship between the type of soil and the effect of M.C.P.A.

Pre-emergence applications appeared to be little affected by the weather on the day of application, but when the weeds were already through the soil heavy rainfall on the day of treatment seemed to reduce the degree of control.

Except in the case of certain species, such as Rumex spp. and *Cirsium arvense*, application prior to emergence or at the very young seedling stage generally gave the best results. For Rumex and Cirsium later treatment was more effective.

2. *Extension trials.*—The detailed field experiments, just described, were supplemented through the willing co-operation of farmers and of Messrs. Plant Protection Ltd. by large-scale extension trials at numerous centres in England and Scotland [9, 28]. Of the 111 trials completed, 63 were in barley, 33 in oats, and 15 in wheat.

Owing to the magnitude of the task it was decided to keep the layout as simple as possible and therefore no attempt at randomization was made. Plots were of 2 acres and approximately square. Five concentrations of 'Agroxone' were tested, applying 1, 1½, 2, 3, and 4 lb. M.C.P.A. in 2 cwt. dust per acre. In order to minimize errors due to the dust being blown from one plot to another, the plots were generally arranged in ascending order of concentration with the untreated plots to windward.

The total number of trials was divided between three teams of field workers, based on the following centres:

Team I. Dunmow, Bury St. Edmunds, King's Lynn, Lincoln, Huntingdon.

Team II. Yeovil, Reading, Cirencester, Leicester, York.

Team III. Exeter, Shrewsbury, Berwick, Perth, Edinburgh, Dundee.

Each team was equipped with a 6-ton International lorry, a 15–17 h.p. Oliver 60 row-crop tractor mounted on pneumatic tyres, a Nicholson Type CMD manure distributor, and the necessary measuring and weighing machines. The lorries and tractors were lent by the Ministry of Agriculture. The distributors, which were of the spinning plate and finger type with 10½ ft. wheel-base, gave an even distribution and reasonably accurate delivery of 'Agroxone' dust at 2 cwt. per acre, the total operation taking about 1 hour per 2-acre plot, allowing for adjustments and emptying the drill between treatments. This type of machine has generally been found to give a better distribution than those with a direct feed, but the wind-boards provided were not quite satisfactory and an 8½ ft. wheel-base would have been more convenient for negotiating farm gateways.

The three teams worked from March 14 to May 26, March 14 to May 19, and March 15 to June 10. During these periods, widely differing types of weather were experienced, varying from bright sunshine with high temperatures, to snow and severe frost. On the whole, the weather encountered in England was exceptionally good from the point of view of the trials, and there were few days when dusting could not be carried out. With Teams I and II, very good weather was experienced from the time of starting until about April 26. During this period there was hardly a wet day, the weather being fine and open with slight to moderate wind. After April 26 the weather broke and wintry conditions with snow and severe frost, followed by rain and wind, were experienced. Conditions gradually improved towards the end of the period. Team III experienced wet, rough weather in its first 3 weeks, but this improved in mid-April. After moving to Scotland on April 20 the weather was generally bad. Of 20 trials completed in Scotland, 13 were begun in heavy rain, and only 3 under dry conditions. May in Scotland was officially described as the wettest for 40 years. High winds were frequent and reached gale force on four occasions between April 21 and May 29. A slight improvement occurred in early June. Temperatures varied widely.

Results.—At the time of application a census of the weed population on the plots was taken by plant-counts. This was followed, approximately 4 weeks after application, by observational records of the general conditions of the weeds, their prevalence, state of growth, &c., together with an examination of the crop for any phytotoxic effect. The results recorded for each weed were then classified under one of the following headings: (i) complete 'kill'; (ii) incomplete 'kill', but some stunting; (iii) no effect.

According to the frequency with which a given weed appeared in each of these categories, it was possible to arrange the weed species in decreasing order of susceptibility (Table 6).

Yellow and white charlock, and creeping and corn buttercup, were all

killed by M.C.P.A. applied at any stage of growth from pre-emergence to flowering or seeding. Chickweed and speedwell, on the other hand, were satisfactorily controlled only when treated at the cotyledon stage.

TABLE 6. *Results of Extension Trials with 'Agroxone', 1945*

Weed species	Total no. of trials	Trials in which reported: Completely killed % — Amount of M.C.P.A. per acre: 1 lb.	1½ lb.	2 lb.	3 lb.	4 lb.	Not killed but affected %	Not affected %
S. arvensis (Yellow Charlock)	83	80	84	98	98	98	..	..
R. Raphanistrum (White Charlock)	41	56	73	80	85	92	..	..
R. repens and *R. arvensis* (Buttercup)	15	6	12	12	26	76	18	6
C. album (Fat Hen)	20	30	35	45	45	60	40	..
S. vulgaris (Groundsel)	4	..	..	25	50	50	25	25
Veronica spp. (Speedwell)	33	6	9	12	27	45	37	18
S. media (Chickweed)	33	3	6	9	24	42	22	36
Papaver spp. (Poppy)	26	4	4	8	24	32	53	15
F. officinalis (Fumitory)	20	..	..	..	10	30	50	15
Sonchus spp. (Sow thistle)	10	..	..	..	10	30	60	10
Convolvulus spp. (Bindweed)	12	..	8	16	16	24	32	40
S. arvensis (Spurrey)	12	..	8	16	16	24	36	40
Cirsium spp. (Thistles)	46	..	..	..	10	21	41	35
A. Cotula (Mayweed)	11	..	..	9	9	9	55	36
Viola spp. (Pansy)	9	..	..	..	10	10	58	32
Polygonum spp.	43	..	..	2½	2½	5	90	5
Lamium and Galeopsis spp. (Dead and Hemp Nettle)	13	..	..	..	..	..	100	..
P. Anserina (Silverweed)	5	..	..	..	..	..	80	20
Rumex spp.	26	..	..	..	..	..	77	23
Myosotis spp. (Forget-me-not)	3	..	..	..	..	..	66	33
S. Pecten-Veneris (Shepherd's Needle)	9	..	..	..	..	..	66	33
S. Cucubalus (Bladder Campion)	13	..	..	..	..	..	30	70
T. Farfara (Coltsfoot)	4	..	..	..	..	..	25	75
G. Aparine (Cleavers)	16	..	..	..	..	..	12	88

The trials yielded but little evidence of the effect of weather on weed control. Good results were reported when the application was made during a dry period and when heavy rain fell a few hours after treatment. In the latter case distortion and malformation of the weeds became noticeable more quickly, apparently because the weedkiller was washed into the soil in appreciable quantities and absorption could take place through the root as well as through the shoot.

Summary

Grouping together the foregoing results, the most easily controlled weeds were *S. arvensis* (Yellow Charlock or Wild Mustard), *T. arvense* (Pennycress), *C. album* (Fat Hen or Goosefoot), and *R. Raphanistrum* (White Charlock, Wild Radish, or Runch). With all these, M.C.P.A. (sodium salt) applied as a dust at 2 lb. of active material per acre gave a high degree of control (70–100 per cent.) without damage to the cereal crop.

Ranunculus spp. (Corn and Creeping Buttercup), *P. Rhoeas* (Poppy), and *A. arvensis* (Scarlet Pimpernel) were effectively controlled by

M.C.P.A. dust at 4 lb. of active material per acre, and *R. Acetosella* (Sheep's Sorrel) and *C. arvense* (Creeping Thistle) at 8 lb. per acre. Young seedlings of *C. vulgatum* (Mouse-ear Chickweed), *S. vulgaris* (Groundsel), *S. media* (Chickweed), *M. inodora* (Scentless Mayweed), *S. arvensis* (Spurrey), *C. segetum* (Corn Marigold), and *V. tricolor* (Heartsease) were effectively controlled by 4 lb. of active material per acre, but older plants were resistant.

F. officinalis (Fumitory), *P. Anserina* (Silverweed), *L. Aphaca* (Yellow Vetchling), *V. hederefolia* (Ivy-leaved Speedwell), *S. media* (Chickweed), and Sonchus spp. (Sow Thistle) were damaged by the dust at 4 lb. of active material per acre, but in general this rate was not sufficient to provide satisfactory control, though a kill or at least prevention of flowering might be obtained under favourable conditions.

The remaining weeds, viz. *P. Convolvulus* (Black Bindweed), *P. aviculare* (Knotgrass), *P. Persicaria* (Persicaria), Lamium spp. (Dead Nettle), Galeopsis spp. (Hemp Nettle), Myosotis spp. (Forget-me-not), *S. Pecten-Veneris* (Shepherd's Needle), *G. Aparine* (Cleavers), *T. Farfara* (Coltsfoot), *S. Cucubalus* (Bladder Campion), and Rumex spp. (Dock), and established plants of chickweed, mayweed, spurrey, heartsease, and corn marigold were resistant to M.C.P.A. dust at the rates tested.

An aqueous solution of the sodium salt of M.C.P.A., sprayed at 100 gal. per acre, was generally more effective in killing weeds than the same quantity of active material applied dry in 1 cwt. china clay or 1–4 cwt. ground chalk per acre. A granular product incorporating sulphate of ammonia, which was tested for use as a combined top-dressing and selective weedkiller, did not prove very successful.

In no case was M.C.P.A. observed to have any corrosive action upon machinery nor to cause any ill effect upon the operators.

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THE PROTEIN QUALITY OF GRASS AS DETERMINED BY THE METHOD OF OSBORNE AND MENDEL

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IN an effort to apply the Thomas-Mitchell [1] procedure to the assessment of the biological values of grass proteins, the authors failed to produce a satisfactory nitrogen-low diet for guinea-pigs. They were no more successful in their efforts to feed rats on a diet in which grass of relatively low protein-content constituted the only source of nitrogen. Henry and Kon [2] have used rats successfully for such work, but the material which they fed contained more than 20 per cent. crude protein. The only alternative was a method involving the measurement of body-weight increase. Work on these lines had already been done by Crampton [3, 4], who, however, did not concern himself solely with protein quality.

So far as we are aware, the procedure of Osborne and Mendel [5] had not previously been applied to the study of protein quality in pasture grass, and we thought that it might be suitable for this purpose. The levels at which various proteins must be included in basically similar diets in order to obtain equal growth-rates, had been determined by Osborne and Mendel, the value of the protein being considered to bear an inverse relationship to the level at which it was contained in the diet. The same workers, in association with Ferry [6], later adopted a modified procedure in which body-weight increase per gramme of protein ingested should be used as a measure of biological value. The assumption was made that, in young animals, increase in body-weight over the period of feeding the experimental diet is wholly determined by protein-intake. The ratio of body-weight increase to protein ingested (R_1) varies with the level of protein in the diet. As the latter rises, the value of R_1 increases, although only up to a certain point; beyond it the feeding of additional protein results in a progressive decline of R_1. The reason for this variation in the ratio is easily understood.

The original method of Osborne, Mendel, and Ferry (loc. cit.) involved determination of the maximum value of R_1, but most later workers have been content to use a fixed level of dietary protein. The method involves the use of a relatively large number of experimental animals for the determination of one value, by reason of the marked differences in absolute body-weight gains made by individuals on the same diet. These differences are much reduced when body-weight gain is divided by weight of protein ingested, but they are still considerable. The extent of such variation is shown by the results of experimental work carried out by Boas-Fixsen [7] and by Osborne, Mendel, and Ferry (loc. cit.). As already indicated, the method requires the use of young animals, and the rat has almost invariably been employed. The male is found to be the better of the sexes in that it is capable of making greater live-weight gains during a given period. Some workers have fed and

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weighed their experimental animals individually, and determined R_1 for each. On the other hand, Chick [8] has treated groups of rats as units.

The diets used must be so compounded that the only limiting factor to growth is protein-content. Hence, in addition to supplying an adequate energy-intake they must contain all those accessory substances known to be essential to the satisfactory nutrition of the animal. The experimental period should not be less than 4 weeks.

The initial purpose of the work described below was to ascertain if there existed any appreciable difference between the protein quality of young ley and that of good permanent pasture grown under similar conditions of soil and climate. Subsequently it was decided to compare cocksfoot and Italian ryegrass, two of the commonest and most valuable of the grassland species. Preliminary trials had shown the rat to be incapable of dealing with diets containing large proportions of low-protein grass. The use of ruminant animals was impracticable, and the choice lay between two small herbivors, the rabbit and the guinea-pig. No particular advantage appeared to attach to the use of the former, which had, indeed, several disadvantages. The guinea-pig was therefore thought likely to prove the most suitable experimental animal, although the literature does not appear to contain any record of its previous use in the Osborne and Mendel method.

Experimental

Materials comparing temporary ley and permanent grass were obtained from the Cockle Park fields of Long Riggs East and Palace Leas, respectively. These two fields are adjacent and on the same soil type; the cutting areas from which samples were obtained are separated only by a hedge. The temporary ley had been directly reseeded in May 1945 after two corn crops, and was of very good quality; the sward contained relatively much red clover; timothy predominated, cocksfoot and perennial ryegrass were present in fair proportions. The permanent grass, also of excellent quality, contained much wild white clover and had been down for at least a century; of the grasses, timothy predominated and was associated with fair proportions of perennial ryegrass and smooth-stalked meadow grass. A little yellow rattle was present. Two cuts were taken from each of these swards, the first on June 20 and the second on August 24, 1947. On both plots the second cut contained much less clover.

Large samples of cocksfoot and Italian ryegrass were obtained from consignments artificially dried by North-Eastern Grass Driers, Ltd., Cornhill-on-Tweed; these grasses were cut at approximately the same stage of maturity.

The ley and permanent grass samples were oven-dried at 60° C., a temperature at which impairment of neither protein quality nor digestibility was considered to be likely. After drying, the grass was ground in a power-mill, using a $\frac{1}{32}$-in. screen. The cocksfoot and ryegrass samples had been milled at the drying-plant, and were rather more finely ground.

In selecting guinea-pigs, young animals of 6–8 weeks of age, of 200–250 gm. live-weight, and of the male sex were preferred. Five pairs were

used in each trial, each pair being litter mates of the same sex, and of approximately the same initial live-weight. Each animal had its own cage. The cages, designed by one of the authors (R.H.A.), were 7 in. high and of diameter 11 in. Each was fitted with an annexe floored with a removable tray, which contained the food-trap, the possibility of food being scattered amongst faeces being thus eliminated. Food-traps were of the hooded type commonly used for rats, but were of a size suitable for guinea-pigs. The animals were fed at 10 a.m. and at 4.30 p.m. Immediately before the former feed, residues from the previous 24 hrs. were weighed and food-intake ascertained in order to determine individual requirements for the succeeding 24 hrs. The food-supply of each pair was adjusted to the level of that animal which had consumed the smaller amount. Weighings of the animals were made on 3 consecutive days at the beginning, and again at the end of the feeding period, weekly weighings being made in the interval.

TABLE 1. *Percentage Composition of the Grass Samples fed*

	Trial I		*Trial II*		*Trial III*	
	Permanent Cut I	*Temporary Cut I*	*Permanent Cut II*	*Temporary Cut II*	*Cocksfoot*	*Italian ryegrass*
Moisture	9·33	10·03	7·92	8·53	7·81	7·85
Ether-extract	1·81	2·24	2·52	2·47	2·71	2·75
Crude protein	12·45	13·31	10·65	12·84	12·47	11·75
Nitrogen-free extractives	43·05	43·32	45·47	45·12	46·75	49·87
Crude fibre	26·00	23·79	25·27	24·31	21·82	18·52
Ash	7·36	7·31	8·17	6·73	8·44	9·26

The protein levels of the diets were fixed at 11, 9, and 10 per cent. in Trials I, II, and III respectively, the object being to provide an adequate amount of nitrogen, and at the same time to minimize, as far as possible, the difference between the amounts of nitrogen-free supplement fed to the two groups in any one trial.

TABLE 2. *Composition of the Diets fed* (*gm. constituent per 1,000-gm. diet*)

	Trial I		*Trial II*		*Trial III*	
Permanent grass, Cut I	883	..	..	..	..	..
Temporary grass, Cut I	..	826	..	..	..	..
Permanent grass, Cut II	..	..	856	..	..	..
Temporary grass, Cut II	..	..	..	701	..	..
Cocksfoot	..	..	..	..	816	..
Italian ryegrass	..	..	..	..	..	863
Starch	81·9	121·8	90·7	221·0	125·1	86·3
Sucrose	11·7	17·4	21·6	45·1	27·6	20·5
Mineral mixture	5·9	8·7	8·6	9·0	9·2	6·9
Fat	17·5	26·1	23·0	23·9	22·1	23·3

A considerable difference between the amounts of energy material supplied, as nitrogen-free supplement, to the two groups during any one

trial was inevitable. It was, however, possible to reduce this difference by adjusting the proportions of the constituents of the supplement so that the additional fat supplied constituted approximately the same percentage of the whole diet in both cases. Such adjustment was made in Trials II and III. Throughout the experimental period each animal received daily 10 mg. of ascorbic acid, and 1 c.c. of yeast extract fortified with aneurin, as used by Kon [9]; these supplements were fed orally by pipette. In addition, each animal received 1 drop of halibut-liver oil every other day, and concentrates of vitamins E and K once weekly. The mineral mixture contained in the nitrogen-free supplement was made up according to the formula of Hubbel, Mendel, and Wakeman [10].

The predetermined amounts of grass and nitrogen-free supplement were weighed out, mixed, and stored separately for each individual animal, thus obviating the risk of individuals in the same group receiving slightly different proportions of the main components of the diet in the event of imperfect admixture which is always a possibility to be reckoned with.

Faeces were collected once daily, as it was proposed to express protein quality not only in terms of protein ingested but as the ratio live-weight gain/protein digested (R_2). They were stored in a refrigerator, and bulked for analysis at the end of every 7 days.

Results

TABLE 3. *Trial I. Protein Quality of First Cuts from Permanent and Temporary Grass*

Protein level 11·0 per cent. Duration of trial 33 days

Animal no.	*Initial live-weight gm.*	*Gain in live-weight gm.*	*Protein ingested gm.*	*Protein quality R_1*	*Faecal protein gm.*	*Protein digested (apparent) gm.*	*Digestibility coefficient of protein*	*Protein quality R_2*
P_1	259·3	84·7	113·0	0·75	51·3	61·7	54·6	1·37
T_1	271·3	108·0	112·5	0·96	49·9	62·6	55·6	1·73
P_2	240·3	87·4	116·1	0·72	50·2	65·9	56·7	1·33
T_2	236·3	94·0	112·1	0·84	46·6	65·5	58·4	1·44
P_3	260·6	73·1	123·2	0·59	60·3	62·9	58·1	1·16
T_3	318·3	79·4	126·6	0·63	56·1	70·5	55·6	1·13
P_4	210·3	79·7	113·6	0·70	50·6	63·0	55·5	1·26
T_4	223·6	104·4	112·9	0·93	48·2	64·7	57·4	1·61
P_5	243·6	71·7	111·4	0·63	52·3	59·1	51·9	1·21
T_5	189·6	101·1	104·9	0·96	48·0	56·9	53·3	1·81

R_1 is the ratio body-weight increase to protein ingested.
R_2 is the ratio body-weight increase to protein digested.

In all cases temporary grass produced the greater live-weight gains, this superiority being particularly marked in three of the pairs. Higher ratios of live-weight gain/protein ingested (R_1) have been obtained for temporary grass in each of the five comparisons. The relatively poor live-weight gain, and low value for R_1, given by animal T_3 was obviously due to the use of a disproportionate amount of its nitrogen-intake for

maintenance purposes; this animal was of considerably larger initial live-weight than its litter mate or any other animal used in the trial. The amounts of protein digested were remarkably close as between paired animals; hence the figures for protein quality, as defined above, were of the same order as those obtained on the basis of protein ingested. The temporary grass proved superior in four out of five cases.

TABLE 4. *Trial II. Protein Quality of Second Cuts of Permanent and Temporary Grass*

Protein level 9·0 per cent. Duration of trial 35 days

Animal no.	*Initial live-weight gm.*	*Gain in live-weight gm.*	*Protein ingested gm.*	*Protein quality R_1*	*Faecal protein gm.*	*Protein digested (apparent) gm.*	*Digestibility coefficient of protein*	*Protein quality R_2*
P_1	218·0	47·3	72·16	0·66	40·66	31·50	43·7	1·50
T_1	189·7	73·6	72·11	1·02	39·30	32·91	45·6	2·24
P_2	165·3	48·7	77·55	0·63	41·56	35·99	46·4	1·35
T_2	189·0	66·7	75·86	0·88	42·86	33·00	43·5	2·02
P_3	192·7	25·3	77·57	0·33	45·92	31·60	40·7	0·80
T_3	237·3	53·4	80·97	0·66	42·10	38·87	48·0	1·37
P_4	265·0	8·3	82·23	0·10	41·74	40·49	49·2	0·21
T_4	292·3	59·7	87·83	0·68	48·18	39·65	45·1	1·51
P_5	208·7	18·0	82·92	0·22	50·58	32·34	39·0	0·56
T_5	206·3	91·7	81·85	1·12	50·15	31·70	38·7	2·89

The initial live-weight figures in this case call for no comment. The animals were rather younger than in Trial I, and were a more uniform lot. Temporary grass produced the greater live-weight gain in all comparisons; in three animals on permanent grass, weight-increase was very low. Owing to this superiority, R_1 was higher for the temporary grass in all cases. The amounts of protein digested were very close in four of the experimental pairs, so that the values of R_2 for temporary and permanent grass bore the same relationship as did those for R_1.

TABLE 5. *Trial III. Protein Quality of Cocksfoot and Italian Ryegrass*

Protein level 10·0 per cent. Duration of trial 35 days

Animal no.	*Initial live-weight gm.*	*Gain in live-weight gm.*	*Protein ingested gm.*	*Protein quality R_1*	*Faecal protein gm.*	*Protein digested (apparent) gm.*	*Digestibility coefficient of protein*	*Protein quality R_2*
C_1	265·0	171·0	128·54	1·33	61·68	66·86	52·0	2·56
I.R.G.$_1$	244·0	157·0	123·39	1·27	76·94	46·45	37·6	3·38
C_2	263·0	142·0	119·59	1·19	65·83	53·76	44·9	2·64
I.R.G.$_2$	217·0	134·0	115·56	1·16	73·68	41·88	36·2	3·20
C_3	247·0	155·0	125·61	1·23	62·44	63·17	49·6	2·45
I.R.G.$_3$	293·0	100·0	120·76	0·84	79·36	41·40	34·3	2·44
C_4	188·0	115·0	93·61	1·23	47·49	46·15	49·3	2·49
I.R.G.$_4$	185·0	108·0	91·28	1·18	64·53	26·75	29·3	4·04
C_5	179·0	135·0	93·31	1·45	42·68	50·63	54·3	2·67
I.R.G.$_5$	200·0	97·0	88·77	1·09	50·90	37·87	42·7	2·56

As in Trial I, one animal (I.R.G.$_3$) was of initial weight substantially above the mean. Live-weight gains generally were good, with cocksfoot superior in every comparison, and showing higher values for R_1. The digestibility of the cocksfoot protein was always greater than that of Italian ryegrass, the coefficients for the former being from 24 to 68 per cent. more than those for the latter; owing to this greater digestibility, three of the five comparisons show Italian ryegrass to have higher values for R_2, the differences in the remaining two comparisons being negligible.

Discussion

The limitations of the Osborne and Mendel method, as used here, are obvious. As opposed to the Thomas-Mitchell procedure, which makes a direct assessment of biological value, it measures something (live-weight gain) which, in the case of the guinea-pig, may or may not accurately reflect protein quality. The dietary requirements of the rat, which has usually been employed, are relatively well understood, so that it is possible to prepare two diets which are nutritionally adequate, and contain only one variable growth-factor, e.g. protein quality. The requirements of the guinea-pig are imperfectly understood, and it is not possible to ensure that any diet contains, in adequate amount, all the factors necessary for growth. It is thus conceivable that guinea-pigs will make body-weight increases which are limited by one or more factors other than the quality of the protein.

The guinea-pig suffers from the same limitation as other laboratory animals, in that its simpler digestive system precludes the direct application of results obtained with it, at least to the ruminant farm animals. It would seem probable, however, that a difference in protein quality which exists for the ruminant will make itself evident, or even be emphasized in, the smaller animal.

Where food-intakes are controlled, as in the work described above, it would seem to be essential that the initial weights of individuals of any pair differ as little as possible. The ill effect of a considerable difference is seen in the results of both Trials I and III, in which animals T_3 and I.R.G.$_3$ respectively were markedly heavier than their litter mates. The lower ratios (R_1 and R_2) given by such overweight animals are presumably due, as already indicated, to the use of a larger proportion of the available protein for purposes of maintenance, and/or to the fact that the animals are approaching the adult stage. Whether the control of food-intake is desirable in work of this kind is open to question. The authors now incline to the opinion that feeding *ad libitum* would have been preferable in the present instance, as the errors arising from inequalities in the weights of litter mates would have been less serious. The overweight animal when fed *ad libitum* will eat more and make the maximum live-weight increase of which it is capable on the diet fed; the error remaining, which is due to increased maintenance requirement, will be relatively small. These views are supported by the recent work of Murray [11], who compared two leguminous proteins, fed both *ad libitum* and controlled. She found that the ratio gain in weight/protein ingested showed no

appreciable difference whichever mode of feeding was employed, even though there were significant differences in weight-gains made. It is obvious, however, that where experimental animals are all of approximately the same weight, a variable food-intake, whether due to a difference in palatability or some other cause, is bound to result in some degree of error. Assuming that the maintenance requirement for the animals is approximately the same, a larger food-intake will necessarily result in a larger proportion of the ingested nitrogen being used for productive purposes; the higher, therefore, will be the ratio. Mitchell [12] has made this clear by citing a hypothetical case.

It is usual to express the results obtained by the method under discussion on the basis of protein ingested, i.e. to calculate ratio R_1. This ratio provides a summation of protein quality, in that it takes account of both digestibility, and efficiency of utilization of absorbed protein. It would seem that the ratio R_2, which is based on protein digested, should provide a better reflection of protein quality as determined by amino-acid composition. The latter has been used by Chick [8] in recent work on the proteins of wheat. It should not be forgotten, however, that some error attaches to R_2 in that faecal nitrogen is in part of body origin. From a practical viewpoint, the ratio R_1 has much to recommend it.

As has already been admitted, it is not certain that existing knowledge of the nutritional requirements of the guinea-pig can wholly justify its use in a method of this kind. There is, moreover, a criticism which can be levelled at the method whatever experimental animal may be employed, viz. that the protein-content of the live-weight increase may vary with the source of dietary protein and other factors. Evidence of such variation has been provided by Hamilton [13], Mitchell and Carman [14], and other workers. The assumption that differences in live-weight gains reflect differences in protein quality is, however, inherent in the method. In view of the difficulties which the authors have so far experienced in attempting to assess the quality of grass proteins by means of small experimental animals, the Osborne, Mendel, and Ferry procedure appears to them to be the most useful method available, more especially where grass of relatively low protein-content is being studied.

Statistical treatment shows the temporary grass to be significantly superior to the permanent grass when protein quality is measured either on the basis of protein ingested ($P = 0{\cdot}01$) or protein digested ($P = 0{\cdot}02$). This superiority appears to be more marked in the autumn than in the spring cut, possibly as a result of deterioration in the quality of the permanent sward rather than of any considerable change in the temporary ley. It should be noted, however, that a comparison of the spring and autumn cuts is not entirely legitimate, as the grass was fed at two different protein levels.

As already indicated, a difference between the amount of supplementary energy material supplied to the groups of animals used for comparing permanent and temporary grass, could not be avoided; this might conceivably be reflected in the differences between the values of R_1 and of R_2. However, animals fed on Italian ryegrass that received a supply

of supplementary energy no larger than those on the permanent grass, made substantially larger weight-increases per gramme of protein ingested or digested. This would seem to indicate that there was at least no inadequacy of energy supply.

Although it is impossible to account with certainty for the difference in protein quality between the permanent and temporary grass, it could be assumed to reflect a difference in the proportions of the species present in each. This assumption implies differences in the amino-acid make-up of species, and it must be admitted that Chibnall et al. [15] and Lugg and Weller [16, 17] have found little evidence that differences exist. It should be noted that the aforementioned workers carried out their amino-acid analysis in protein preparations of a fairly high degree of purity, although Lugg and Weller have produced some evidence to show that these preparations were representative of the grass protein as a whole. Furthermore, it seems to the authors that there is no certainty of any close relationship between the amino-acid constitution of a plant-protein, and that of the digested fraction. The differences in protein quality found to exist between cocksfoot and Italian ryegrass, and discussed below, do not suggest any marked similarity between the amino-acid make-up of the protein either as it is contained in these two species, or after digestion. The evidence does not appear to invalidate the original assumption, viz. that differences in protein quality found to exist between temporary and permanent grass are due to species differences. If this assumption be accepted, then the superiority of the temporary to the permanent ley on the first cutting occasion may have been due to the somewhat larger amount of clover in the former; the fact that this clover was of the late-flowering red type, whilst that in the latter was wild white, must be noted. In the second cut, the difference between the clover-contents of the two was more marked, and would appear to have been the obvious cause of the difference in protein quality. It should be emphasized, however, that this work provides no evidence of this cause.

The protein quality of the permanent grass, as assessed by both R_1 and R_2, appears to have fallen markedly during the interval between the two cuts, but the temporary grass shows some evidence of a rise. These changes were concurrent with a fairly marked fall in the clover-content of the former. As already indicated, the two cuts were fed at different protein levels, and it is not proposed to do more than draw attention to these apparent differences. Morris, Wright, and Fowler [18] have concluded from their experimental work with cows that the protein of pasture-grass has a markedly higher value for milk production in spring than in autumn. The character of the sward from which their grass was cut is not, however, very precisely defined, and the results which have been obtained in the course of the present work, suggest that it might be unwise to assume that grass from swards of all types necessarily deteriorates in respect of protein quality as the season advances.

The evidence relating to species differences provided by this work is limited to two grasses only; nevertheless, it does suggest that such differences exist. The value R_2, which can be related only to amino-acid

make-up, indicates that Italian ryegrass is superior to cocksfoot.[1] On the other hand, the digestibility of the latter is greater than that of the former to such an extent as to give a higher value for R_1. Thus, it would appear that, pound for pound, cocksfoot may be a more effective source of protein than Italian ryegrass. The digestibility coefficients used here were obtained with guinea-pigs, as were the remainder of the experimental data; it is obviously uncertain whether conclusions drawn from such data will apply to ruminant farm animals.

Summary

1. Comparisons of the protein quality of grass from temporary and permanent leys, and of two individual grass species, have been made by means of the Osborne, Mendel, and Ferry technique, with guinea-pigs as the experimental animals.

2. The advantages and disadvantages of the guinea-pig for this work are discussed.

3. Protein quality was assessed on the basis of body-weight increase/protein ingested (R_1), and body-weight increase/protein digested (R_2). Both means of assessment were considered to be of value.

4. The method as used here, although admittedly imperfect, does provide a means of investigating the protein quality of grass of relatively low grade.

5. Grass from a temporary ley was shown to have a higher protein quality than that from a permanent sward, both early and late in the growing-season.

There was some evidence that the protein quality of the permanent grass fell as the season advanced, and that the initial quality of the temporary grass was maintained.

6. Of the two individual species investigated, viz. cocksfoot and Italian ryegrass, the former proved to be superior as measured by R_1, but inferior by R_2.

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A SURVEY OF MINERAL DEFICIENCIES IN CROPS ON ARABLE LAND IN TWO ENGLISH COUNTIES

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DURING the last few years a field technique based on symptomology and tissue tests has been developed for determining the nutritional status of crops [1]. The use of this method of surveying tillage such as is found in an English county was tried for the first time in Herefordshire during 1945 and subsequently in Somerset during 1946. From such surveys it is possible to draw conclusions regarding the fertility, in respect of nutrient deficiencies, of the tillage area in these counties, thus enabling comparisons to be made with the results of soil analyses. Previous attempts to determine the nutrient condition of soils in Somerset and Herefordshire have been made by 'Fertilizer Practice' [2], which is a method based on the quantitative determination of soil samples and a knowledge of the amount of fertilizers used on crops and grassland.

Sampling methods.—The farm samples chosen for these surveys represented 2 per cent. of all farms over 10 acres. In order to balance the sample correctly a random selection was made within the acreage groups 10–50, 51–150, 151–300, and 300 plus. The number of farms involved in each county is shown in Table 1.

TABLE 1

County	*Crop acreage (000's)*	*Holdings of 10 acres and over*	*Farm sample*
Hereford	136	4,269	74
Somerset	167	9,108	143

Inspection of crops.—The inspection of the farm crops was carried out for cereals in May–June; for potatoes in July–August; and for sugar-beet, roots, and kale in September–October. The approximate yields at harvesting of sampled crops were recorded for Herefordshire.

Evaluation of diagnostic methods.—The two methods used in assessing the nutrient status of a crop were, 'visual' [3] and 'tissue-tests' [4, 5]. The determination of a soil pH by the B.D.H. soil indicator was frequently done in conjunction with problems of acidity and micro-nutrient deficiencies.

As one technique is complementary to the other it is necessary to convert the working standards of each into one applicable to both. For example, micro-nutrient deficiencies are diagnosed entirely by symptoms because tissue-tests for Mn and B are unsatisfactory for field work, whilst, on the other hand, the differentiation between N and P deficiencies in cereals is difficult using symptoms, but comparatively easy by the use

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of tissue-tests. A list of the standards and deficiency categories adopted for any nutrient are shown in Table 2.

TABLE 2. *Evaluation of Two Diagnostic Methods for any Nutrient*

'Visual' method		*Equivalent conversion standard*		*'Tissue-tests' method*
Symptoms severe	=	Low*	=	Low
Symptoms medium	=	Medium*	=	Medium
Symptoms absent	=	Satisfactory	=	High

* Deficiency levels.

Evaluation of crop yields.—To make comparisons between the nutritional condition of a crop and its yield the approximate standing or harvested yield of the crop was estimated. A list of the categories into which the yields are grouped and their equivalent standards are shown in Table 3.

TABLE 3. *Evaluation of Crop Yields*

Crop	*Yield categories*			
	Extremely low	*Low*	*Medium*	*Satisfactory*
Cereals (cwt.) . . .	8	9–14	15–19	20
Sugar-beet (tons) . .	4	5–6	7–9	10
Potatoes (tons) . . .	3	4–5	6–8	9
Mangolds (tons) . .	7	8–14	15–24	25
Swedes and turnips (tons) .	4	5–6	7–9	10

Climate.—The range in annual precipitation in Herefordshire is considerable. The more mountainous regions of the western side of the county have an annual rainfall of 32–6 in., compared with 25–30 in. in the central and eastern areas. During 1945 the incidence of rainless periods was low and no droughts occurred. On the whole the season was excellent for plant-growth.

The range of annual precipitation in Somerset shows a wide variation from 25 to 40 in. During 1946 there were no periods of drought. The high rainfall during the summer months and the decrease in sunshine were two factors responsible for creating unusual growing conditions. Cultivations aimed at checking weeds were quite inadequate, and the weeds grew at the expense of the crops which in turn developed all the symptoms of nitrogen deficiency.

Soils.—The soils of Herefordshire are derived mainly from the Old Red Sandstone and Silurian formations, and vary from light to medium loams. The soils of Somerset are as varied as those of any county in the country and include light loams, heavy loams, clays, and peats, involving a wide range of geological formations from Pleistocene to Devonian.

Statistical results.—When the crops inspected were examined for deficiencies known to occur in England, it was found that shortages of magnesium and manganese were not apparent on the farms visited. For this reason the following Tables exclude these two elements. The

figures in the numerical Tables are based on raised samples obtained by multiplying the samples by the reciprocals of the sample fractions.

Deficiencies and Crops in Somerset and Hereford

The incidence and severity of deficiencies found in the principal crops are shown in Table 4. The description of a deficiency as being either in a 'low' or 'medium' category is taken from Table 2, which classifies a deficiency at one of these two levels.

TABLE 4. *Percentage Acreages of Deficiencies for Different Crops as based on Tissue-Tests and Symptoms*

	Est. acreage (000's)	N		P		K		Ca*		B	
		L	*M*	*L*	*M*	*L*	*M*	*L*	*M*	*L*	*M*
HEREFORD											
Wheat	36	3	17	5	32	..	..	..	..	..	..
Barley	32	..	3	..	14	..	..	..	..	..	..
Oats	35	3	8	..	20	..	..	..	..	..	..
Potatoes	11	..	7	..	..	..	7	..	..	..	..
Sugar-beet	6	8	1	2	..	..	..	4	..	1	4
Mangolds	5	..	11	..	5	..	5	1	..	..	2
Swedes and turnips	11	..	8	..	6	..	..	..	2	..	..
SOMERSET											
Wheat	50	3	15	..	27	..	..	..	..	..	..
Barley	31	..	15	2	21	..	..	..	..	..	..
Oats	31	6	10	3	19	..	..	..	..	..	..
Mixed corn	13	4	7	..	15	..	..	..	..	..	..
Beans	3	..	..	..	17	..	20	..	..	..	..
Potatoes	8	2	13	..	8	..	16	..	..	..	..
Swedes and turnips	11	11	17	..	1	..	..	0·2	..	..	..
Mangolds	11	..	21	..	..	..	..	0·1	..	..	..
Sugar-beet	2	..	3	..	..	..	..	..	..	..	..
Kale and cabbage	8	10	28	..	2	..	..	..	..	..	..

Notation: L = low, M = medium deficiency levels.

* Implying acidity and not differentiating between calcium deficiency and manganese toxicity.

The data in Table 4 indicate that for Hereford deficiencies of N were found in all crops. Percentage deficiencies for other nutrients were: P, mostly in cereals, 20–37 and roots 2–6; K in potatoes and mangolds 5–7; Ca in sugar-beet and roots 1–4; and B in sugar-beet and mangolds 1–4. Similarly, for Somerset, deficiencies of N were found in all crops excluding beans: P in cereals 15–27; potatoes 8 and roots 1; K in potatoes and beans 16–20; and Ca only in roots 1.

Deficiencies based on districts.—In Herefordshire the farming divisions between hill and vale are hardly separable since much of the top and bottom land run together; on account of this it is impossible to

differentiate districts in this county. On the other hand, Somerset having a wide range of farming regions lends itself more readily to analysis on a district basis (Table 5).

TABLE 5. *Percentage Acreages of Deficiencies in Each Farming District of Somerset*

	N		P		K		Ca	
Type of farm	*L*	*M*	*L*	*M*	*L*	*M*	*L*	*M*
Dairying—arable .	2	16	..	21	..	0·5	..	..
Arable—dairying .	..	13	..	14	..	1	..	..
Hill farms . .	10	16	2	12	..	1	0·5	..

L = low, M = medium deficiency levels.

It can be seen that while N deficiency was widespread in each farming area during the wet summer of 1946, it was more extensive in the hill areas; also that the dairying-arable region was markedly short of P. The hill-farming districts containing about a tenth of the arable land in the county are the least suitable for growing crops, and although this is the only area showing acidity problems, the extent of the trouble is not marked.

Deficiencies and crop yield.—The relationship between crop yield and the incidence of deficiencies is given for Hereford in Table 6. The acreage of each crop is subdivided into different yield levels (Table 3) and against each level is shown the incidence of deficiencies.

It is noticeable that over 50 per cent. of the crops yielded satisfactorily and yet showed deficiencies, although negligible, of N, P, K, and B. For instance, potatoes which cropped at 10 tons to the acre recorded 12 per cent. K deficiency, and 6 per cent. of the sugar-beet yielding 10 tons to the acre were deficient in B. Of the tillage with 'low' or 'extremely low' yields the deficiencies of N and P rise to 60 per cent., but only 1 per cent. of this low-yielding category was affected by Ca deficiency. It is also evident that low yields are mostly, but not entirely, explicable in terms of macro- or micro-deficiencies.

The occurrence of N and P deficiencies together was noted particularly in crops when yields were 'low' or 'extremely low', and were invariably associated with poor farming in all its many aspects.

Overall deficiencies for the two counties.—Table 7 shows that when the incidence of deficiencies on tillage land are summarized the chief shortages are those of N and P. The unusually high incidence of N deficiency in Somerset during 1946 was partly due to the wet season. The agreement between the P figures (20 per cent.) in both counties may indicate similar husbandry practices in the use of phosphatic manures. In contrast, the incidence of K deficiency is low, and likewise is the same in both counties. Calcium deficiency or the problems associated with the acidity complex record a negligible figure for Hereford (0·5 per cent.) and a zero value for Somerset. The incidence of micro-nutrient deficiencies was low and concerned only boron.

TABLE 6. *The Relationship between Crop Yields and the Incidence of Deficiencies in Herefordshire**

Crop	Yield	Crop acreage %	N		P		K		Ca		B	
			L %	M %	L %	M %	L %	M %	L %	M %	L %	M %
Wheat	Satisfactory	45	..	4	3	..	..	..	..	..	..	..
	Medium	31	..	6	..	43	..	..	..	..	..	..
	Low	19	..	70	..	79	..	..	..	..	..	..
	Extr. low	5	66	..	73	..	..	..	..	..	..	..
Barley	Satisfactory	61	..	4	..	..	..	..	..	..	..	..
	Medium	31	..	..	..	..	..	..	..	..	..	..
	Low	8	4	..	..	63	..	..	..	..	..	..
	Extr. low	..	..	100	..	..	..	..	..	..	..	..
Oats	Satisfactory	41	..	5	..	5	..	..	..	..	..	..
	Medium	39	2	12	..	30	..	..	..	..	..	..
	Low	14	..	1	..	..	..	..	..	..	..	..
	Extr. low	6	36	..	..	63	..	..	..	..	..	..
Potatoes	Satisfactory	48	..	..	..	..	..	12	..	..	..	..
	Medium	39	..	4	..	1	..	3	..	..	..	..
	Low	13	..	42	..	..	..	..	..	..	..	..
	Extr. low	..	..	..	..	..	..	..	..	..	..	..
Sugar-beet	Satisfactory	81	..	..	..	..	..	..	..	..	..	6
	Medium	8	..	11	..	..	..	..	..	..	..	..
	Low	8	..	..	..	1	..	..	75	..	25	..
	Extr. low	3	100	..	22	..	..	..	..	..	..	..
Mangold	Satisfactory	45	..	..	..	..	..	..	..	..	..	..
	Medium	40	..	7	..	..	..	12	..	..	..	5
	Low	10	..	42	..	42	..	..	..	5	..	..
	Extr. low	5	..	78	22	..	..	..	22	..	..	..
Swedes and mangolds	Satisfactory	65	..	..	..	..	..	..	..	..	..	..
	Medium	28	..	..	..	21	..	..	..	8	..	..
	Low	7	..	100	..	..	..	..	..	..	..	..
	Extr. low	..	..	..	..	..	..	..	..	..	..	..
All crops	Satisfactory	69	..	3·1	0·7	1·0	..	0·9	..	..	..	0·4
	Medium	45	0·4	6·0	..	12·7	..	0·8	..	0·5	..	0·2
	Low	18	0·2	34·9	..	69·5	..	..	1·5	0·3	0·5	..
	Extr. low	4	58·0	7·3	29·3	29·0	..	..	1·2	..	..	..

L = low, M = medium deficiency levels.

* The data in this Table have been set out in the form of histograms, which may be seen on application to the author.—Edit.

TABLE 7. *Incidence of Deficiencies on Tillage Land in Hereford and Somerset*

County	Total crop acreage (000's)	N %	P %	K %	Ca %	Mn %	B %
Hereford, 1945 .	136	10·0	20·0	1·0	0·5	0·0	0·3
Somerset, 1946 .	167	18·0	19·0	1·0	0·0	0·0	0·0

Conclusions

Hereford.—As a land unit, apart from the more mountainous areas on the periphery of the county, Herefordshire is well suited for arable farming in respect of climate, soils, topography, and husbandry.

The policy of taking the plough round the farm has encouraged the use of lime, fertilizers, and indirectly endowed the farmer with accumulative experiences of arable husbandry. The results of this survey, therefore, must be viewed with these facts in mind.

The survey shows, for example, that acidity is no longer a serious limiting factor to crop growth, a fact undoubtedly due to a systematic liming policy. It is noteworthy that as a consequence of this practice, occasional over-liming has induced boron deficiency to the extent of 5 per cent. in the sugar-beet crop. There is no reason why the incidence of this deficiency should increase if a judicious use of lime prevails.

At a lower level of farming husbandry the incidence of nitrogen deficiency increases considerably and the remedy for such conditions lies essentially in the application of good husbandry rather than a high level of manuring. On the other hand, there is a need for the increased use of nitrogenous fertilizers, particularly for spring dressings to cereals. Similarly, it is suggested that one-fifth of the tillage which was shown to be phosphate-deficient would benefit from dressings or increased dressings of phosphatic manures.

In summing up the significance of potash as a nutrient it is important to realize that while in a dry season the incidence of this deficiency would increase, the rise would not be appreciable, since the two most susceptible crops, potatoes and mangolds, occupy only 10 per cent. of the arable land. As the root-break is liberally supplied with farmyard manure the potato crop remains the principal recipient for further potash manuring.

Somerset.—The last six years of arable husbandry before 1946 witnessed the plentiful use of lime, the increased use of fertilizers and, as a consequence of experience, a more practical use of tillage land. Considering these three factors in relation to the particular season of 1946, which was unduly late and wet, the significance of the estimated deficiencies can be judged accordingly.

The extensive deficiency of nitrogen in all crops and districts reflects the influence of the season. Indirectly, however, a nitrogen-starved crop requires less potash and this in turn would affect the degree of incidence of potash as was the case in this survey. Even so, the increase would not be appreciable since potatoes, the one crop most likely to suffer from a shortage, occupy only 5 per cent. of the tillage in Somerset.

The 30,000 acres of phosphate-deficient land concerns chiefly cereals and as an estimate is perhaps least affected by external factors.

A vigorous liming programme appears to have largely eliminated soil acidity so far as it may be a serious limiting factor to crop production. It must be remembered, however, that the hill-farming areas of Somerset—Mendip and Exmoor—have a high rainfall and do not grow any

considerable acreage of barley or any sugar-beet, both crops readily succumbing to a low soil pH.

The absence of micro-nutrient shortages in the county does not imply that they never occur. Actually the 'flats' of Somerset are situated on clays with a high base-status and manganese deficiency in oats is frequently recorded [6]. Similarly, the Keuper sandstone areas of the Taunton vale have suffered from boron deficiency in sugar-beet [6]. It seems, however, that the selective cropping of fields prone to manganese deficiency, and the small acreage of sugar-beet grown on potential boron-deficient soils, together with a wet season, were factors instrumental in eliminating shortages of these elements during 1946.

In both counties the war-time allocation of phosphates was inadequate in relation to needs: potash fertilizers, indirectly supplemented by the use of farmyard manure, were available in amounts almost sufficient for crop requirements, and the spreading of lime appeared to be on a scale sufficient, at least, to eliminate crop failures due to acidity. It should be noted that the extensive phosphate deficiency recorded might in some degree be associated with low soil pH, but this point is outside the scope of this work. Fertilizer practice [2] showed that whilst new arable required more P than old arable, the allotted amounts of P (0·1 per cent. P_2O_5 for cereals) were being taken up by the farmers; they found that potash was not being fully utilized and pointed out that the soil analyses of K were to a large extent low. This, however, was not borne out by the above surveys. Similarly, they considered acidity to be more instrumental in reducing fertility than reported here. However, as the mineral deficiency surveys were carried out 3 years later, the amount of lime applied had increased considerably.

As a soil must be considered in relation to the crop it is growing, a mineral-deficiency survey (as described) has much in its favour and relative to 'Fertilizer Practice' probably defines more accurately the nutrient status of arable crops. On the other hand, it has definite limitations since its terms of reference are confined to tillage land. It would seem that the ideal survey should be so designed that both methods could be incorporated, each being complementary to the other.

Summary

1. A description is given of a nutritional survey of farm crops to assess deficiencies of nitrogen, phosphate, potash, calcium, manganese, and boron.

2. The nutrient condition of a crop was diagnosed by the use of two complementary methods, (*a*) 'visual' and (*b*) 'tissue-tests'.

3. In both counties nitrogen and phosphate deficiency were widespread; potash deficiency was confined to potatoes and beans, acidity was observed only in roots, whilst micro-nutrient deficiencies were confined to sugar-beet (Hereford only).

4. Overall statistics for the counties showed that in Hereford 18 per cent. of the tillage was deficient in nitrogen, 19 per cent. in phosphate, and 1 per cent. in potash; in Somerset 10 per cent. was deficient in nitrogen, 20 per cent. in phosphate, and 1 per cent. in potash.

5. In general, the results of these surveys suggest that a more rational use of fertilizers would involve the increased use of nitrogen for all crops and of phosphorus for cereal-growing; increased dressings of potash to potatoes; the use of lime only where soil tests show an overriding need, and avoidance of over-liming, which on certain soils induces boron deficiency.

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SOME ASPECTS OF LONGEVITY IN DAIRY COWS

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MUCH interest is now being shown in the length of the productive life of dairy cows. It is argued that in the quest for higher yields, the value of a long productive life is overlooked. In particular, it is frequently said that the average productive life of cattle is at present deplorably low and that its improvement would raise the national average milk-yield by increasing the proportion of cows in the high-producing age-groups. In this paper we shall consider the importance of longevity, mostly from the aspect of economic value in commercial herds, and show that neither the pessimism about the present situation nor the optimism about the effects of a future improvement is justified.

Estimation of Average Productive Life

Discussion of longevity has not been made any clearer by the frequent confusion of the average productive life of the cow with average milking-age of the population in terms of time since first calving. The distinction can be illustrated simply by reference to the human population of Great Britain, in which at the moment the expectation of life is around 65 years, although the average age of the population is close to 35. In general, it is true that if wastage-rate increases with age, as it does in most populations, then the expectation of life is greater than the average age and vice versa. Pettit [1] and Donald and El Itriby [2] have pointed out that this error has been frequently made in the past. In a stable population—one in which the total number and age-distribution are constant—the expectation of life is easily calculated from the replacement rate. If one-quarter of the population is replaced each year, then obviously the expectation of life is 4 years.

Pettit [1], in discussing the longevity of cattle in a group of commercial herds in East Anglia, has used this method to arrive at a figure of 4 lactations for the average productive life of the dairy cow, and Hammond [3] similarly gives a figure of $4\frac{1}{2}$ lactations. The situation is slightly complicated since none of the populations was really self-contained. If the group concerned sells more cows in milk than it buys, then the average life will be under-estimated by this method and vice versa. Donald and El Itriby [2] have studied a population which can import no cows in milk into the group (pedigree Red Poll herds), and conclude that the average productive life is 3·8 years; this is almost certainly an under-estimate, as many cows will be sold to non-pedigree herds while still in milk.

More recently the figures quoted have been less than those above. In its 1947 report [4], the Bureau of Records of the Milk Marketing Board made a survey of lactations from recorded herds and stated 'An examination of 68,000 lactations shows that the working life of a cow in

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a herd is 3·1 lactations.' Hammond [5] has given a figure as low as $2\frac{1}{2}$ lactations.

However, the Milk Marketing Board's figures for the age-distribution (Table 1) show that the old confusion between average age and expectation of life has crept in.

TABLE 1. *Age-distribution of Cows in Milk* (*M.M.B.* 1947)

	All breeds		*All breeds*
1st Lactation (heifers)	25·6	6th Lactation	5·7
2nd ,,	21·6	7th ,,	3·1
3rd ,,	16·9	8th ,,	2·1
4th ,,	13·8	9th ,,	1·2
5th ,,	9·2	10th ,, and over	0·8

The figure of 3·1 is actually the average age of the population in terms of times calved. Since 25·6 per cent. of the lactations are from heifers, the average productive life is 3·9 lactations. As the group of recorded herds, from which these data are obtained, is probably on balance exporting, this may well be a slight under-estimate.

It might be expected on other grounds that the more recent figures quoted are on the low side. We know from records of fertility, sex ratio, calf mortality, &c., that it is only once in three calvings that a cow produces a heifer calf which reaches a lactation. If all dairy cows were mated to dairy bulls and all their surviving heifer calves entered dairy herds, the replacement-rate would be at most $\frac{1}{3}$ per year. In fact, however, many dairy cows are mated to beef bulls, so that their offspring are not available as replacements for a dairy herd, and some potential dairy heifers are sold fat so that the potential replacement-rate of $\frac{1}{3}$ per annum is never reached. Even though the losses due to the use of beef bulls on dairy herds and the fattening of dairy heifers were small, if the dairy-cow population is to remain constant in size, the average productive life must be at least 3 lactations. In fact, the dairy population has been increasing slightly, so that the average productive life must be more than 3 lactations. If the expectation of milking-life were only $2\frac{1}{2}$ years, replacements at the level of 40 per cent. would be needed [6], whereas not much more than 33 per cent. can be available.

In the light of present evidence, therefore, we see no reason to question the conclusions of Pettit and Donald and El Itriby that the average productive life is approximately 4 lactations.

The Economic Value of Longevity

In commercial milk production, a longer milking-life may increase profits in four ways:

(*a*) by reducing the annual cost of replacements per cow in the herd;
(*b*) by increasing the average herd-yield through an increase in the proportion of cows in the higher producing age-groups;
(*c*) by reducing the replacements which have to be reared, and therefore allowing an increase in size of the milking herd for a given acreage;
(*d*) by an increase in the culling possible.

The last two categories are to some extent mutually exclusive in that a farmer can either make use of the longer life to reduce the number of followers in the herd, or he can keep the same number of followers as before and cull more heavily when they reach maturity. We shall first discuss categories (*a*), (*b*), and (*c*), as they are likely to be more applicable to the ordinary commercial herd.

(*a*) *Replacement cost.*—The following discussion of the economic side of milk production is based on the many regional reports of the national milk-costs investigation. These reports include a detailed costing of milk production per cow and per gallon in a large number of commercial herds. As examples we may cite the investigations of milk costs in the west country by the Bristol University Department of Economics [7], and in the north-west of England by the Manchester University Agricultural Economics Department [8].

The many reports are in very fair agreement in showing a division of the total percentage costs into separate items as follows: food 50, labour 25, 'overheads' 17, replacement 8.

The replacement costs are obtained from the expenditure on purchased cows (at cost price) and the estimated cost of production of home-reared heifers minus the returns from the sale of outgoing cows. The proportion of replacements bought in varies in different regions but seems to be about $\frac{1}{3}$ to $\frac{1}{2}$. The purchased cows are in general more expensive than the home-reared heifers, but the difference is small [9]. Imper and Anderson [10] state that 'the cost of replacement is slightly higher in those herds maintained by purchase and the production slightly less compared with the self-maintained herds'.

The total annual cost per cow in the reports studied is about £50, and the annual replacement cost per cow in the herd is about £4. As a quarter of the cows are replaced each year, the total loss on turnover of each cow is in the neighbourhood of £16. If the average milking-life were increased to 5 lactations, the average annual cost would decrease to £3·2 per cow. Thus an increase of one lactation in productive life would increase the annual returns by about 16*s.* per cow.

(*b*) *Effect of an increased productive life on herd average.*—As mentioned above, an increase in productive life would be expected to increase the herd average by giving a higher number of cows in the high-producing age-groups. It is fairly easy to calculate the magnitude of this effect. For this purpose we have used the age-corrections evaluated for a large sample of Ayrshires in Scotland by Sikka [11] using the paired lactation method. The results are given in Table 2.

The relative yield in each lactation is shown in the second column and the third column shows the average yield per lactation for cows living to the end of 1, 2, 3, &c., lactations. It will be seen that the highest yield is given in the fourth and fifth lactations, the highest average per lactation over the cow's life (col. 3) is given by cows surviving to the end of the seventh lactation; and cows living to complete more than 7 lactations have lower averages.

To estimate the effect of longevity on herd average, it is first necessary to calculate the age-distribution on different assumptions of mortality.

TABLE 2. *Effect of Age on Yield (Ayrshires)*

Lactation	*Relative value*	*Cumulative mean*
1	85·05	85·05
2	92·89	88·97
3	97·70	91·88
4	100·00	93·91
5	100·31	95·19
6	99·15	95·85
7	97·06	96·02
8	94·54	95·96
9	92·13	95·54
10	90·34	95·02

We have assumed that the wastage-rate is one-sixth for the first and second lactations and will rise in later lactations to a rate independent of lactation. We have made the calculation for 5 different wastage-rates chosen arbitrarily. Table 3 gives the average age and relative herd mean milk-yield for the different wastage-rates.

TABLE 3. *Effect of Expectation of Life on Herd Mean Yield*

Wastage-rate after 2nd lactation	*Expectation of life*	*Relative herd mean yield*
0·2	5·31 lactations	100
0·3	4·15 ,,	99·9
0·4	3·57 ,,	99·6
0·5	3·22 ,,	99·1
0·6	2·99 ,,	98·6

The effect of the variation in expectation of life on herd mean yield is small, largely because, however long cows may live, the early age-groups always contain more cows than the later ones. It can be shown that even the highly imaginary herd of cows surviving to the end of the seventh lactation and then being got rid of, has a herd mean of only 102·4. A herd with a wastage-rate of 0·33 and average yield 99·8 would have an age-distribution very similar to the Milk Marketing Board's sample in Table 1. The actual detailed results depend on the assumptions made in the construction of the age-distribution. However, it would seem reasonable to conclude on the bases of other calculations that an increase in the expectation of milking-life to 6 lactations would not raise the herd mean by more than 1 per cent., that is 5–6 gal. a year at the present national level. The profit from this rather meagre advance must be added to that due to the reduction in replacement-rate.

(*c*) *Size of the milking herd.*—If a farmer replaces only one-fifth of his herd each year instead of one-quarter, he need have fewer followers to provide the necessary replacements. In a herd of, say, 20 cows the number of replacements will be reduced from 5 to 4 per annum. In place of these, it should be possible to keep an extra milking cow and

add, say, £25 to the total annual profit of the herd. This gives an extra return of about £1. 5*s*. per cow.

One may compare these extra returns with that to be expected from an increase in yield. The milk-cost investigations, referred to above, indicate that in the range of 500 to 700–800 gal. a year, an increase in herd average of 100 gal. means an extra profit of about £7 per cow. It appears that above the level of 700–800 gal., although profit per cow continues to increase with yield, there is a tendency for this increase in profit to be at a continually diminishing rate. However, the great majority of commercial herds probably lie within the above range. The increased returns due to the increase in milking-life of one year are, therefore, as follows: replacement costs, 16*s*. per year; herd mean yield, 8*s*. (corresponding to an increase of 6 gal.); increase in number of milking cows, 25*s*. The total increase in profit would thus be about £2. 10*s*., equal to that produced by an increase in herd average yield of 35 gal. Although in these calculations the economics of milk production may have been rather over-simplified, it is likely that the conclusions reached are roughly correct. In addition, it must be observed that the milk-cost investigations refer to a national herd predominantly dual purpose in type at a time when the carcass value of a fat cow is relatively high. The detailed conclusions would not be expected to hold for, say, Jersey herds. It seems likely that the relative costs of food, replacement, &c., are roughly the same as before the war [12]. The balance is so much on the side of yield in these results that from the commercial dairy farmer's point of view, longevity is of secondary importance compared with a satisfactory level of milk-yield.

Effect of Culling on Average Productive Life and Herd Mean

In addition to the wastage forced upon him by constitutional weakness and disease, the farmer may choose to dispose of animals because their performance is below standard; these animals will be referred to as 'culls'. The distinction is perhaps a little artificial, but it must be made in any discussion of the question. For the sake of simplicity, we shall assume that all culling is done at the end of the first lactation and is based on performance in that lactation. The effect of culling will be to reduce the average life in the herd by increasing the effective wastage in the first lactation, and also to increase the level of production in later lactations. The increase in any later lactation produced by culling in the first lactation is simply calculated from the amount of culling done and the extent to which superiority in the first lactation is repeated at later ages. Figures for the latter are available from the work of Sikka [11] in the form of the regression coefficients of later lactation yields upon the first. The average yield of heifers is of course unaffected by the culling. Application of these figures to the imaginary herds with age-distributions as already calculated in Table 3 gives an estimate of the average herd yield at different levels of culling. Fig. 1 shows the effect of culling[1] on different assumptions of wastage. At the present level of wastage,

[1] Culling percentage here and elsewhere refers to the proportion of heifers culled on their first lactation performance.

for instance (i.e. at about 0·33 in the figure, with an average life of 4 lactations and an average yield of 99·9), culling at a level of 20 per cent. decreases the average life to 3·3 lactations and increases the average yield

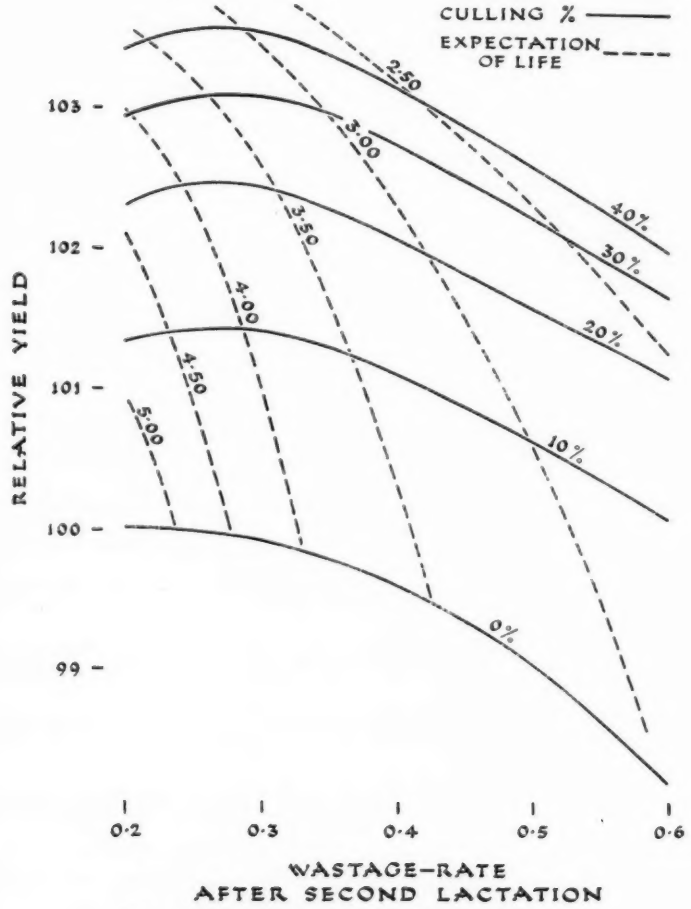

FIG. 1. Effects of culling at varying wastage-rates.

to 102·4. Culling will reduce the average expectation of life, and its value depends on the average yield of the herd and the value of the culls when sold. The actual amount of extra milk produced by culling will be greater in the higher-producing herds, and the value of the culls will depend on the type of herd from which they are culled. The profitability of culling will depend on the balance between these two factors.

Discussion

The foregoing calculations indicate that an improvement in longevity is a matter of less importance and urgency in milk production than might have been expected. First, the expectation of productive life is about 4 years and not 3 or less as has been suggested recently. Far less general concern would be felt on the subject if this were more widely realized. Secondly, herd average yield is very little affected by changes in average productive life, so that the argument that longevity is valuable because it enables the farmer to have a higher proportion of his cows at the most productive age, though strictly true, has so small an effect that it can be ignored. Thirdly, increasing the average expectation of life by 1 year reduces the cost of replacement and increases the holding of cows per acre by an amount which is equivalent in cash to an overall increase of milk-yield of about 35 gal. per cow. This would seem to justify the breeder in placing emphasis on lactation-yield rather than length of productive life.

High production is not likely to be achieved by weak and unhealthy animals and it would seem to be reasonable to expect high yield to go hand in hand with healthy stock. Nevertheless, if it could be shown that selection for high yield produced animals genetically of short life, there would be reason for caution in selecting for increased yield. There is some evidence that the cows which produce well in early lactations do not live quite as long as the moderate producers, but the effect is very small and it is not known to what extent the result is genetic rather than environmental. Of course in normal practice there is inevitably some selection for longevity, as cows which die young leave fewer offspring.

Though longevity as such can be shown to have little economic value compared with high yield, it does not follow that freedom from disease and constitutional well-being are not important characters. As has been pointed out before, health and longevity are not the same thing. Few cows die a natural death, and if the farmer's standards were to rise as the health and performance of his animals improved, such an improvement might have no effect at all on the average productive life of his herd. It would be unfortunate for this reason if longevity should be used as a measure of health in dairy cows, for freedom from disease is obviously of the greatest importance if for no other reason than its effect on yield.

We have been dealing above with the question of longevity from the point of view of the commercial milk producer only. The breeder, who relies on the sale of female stock at a price well above their rearing cost for part of his income, is in a completely different position. For him, cutting down of wastage to the minimum, more especially in the period of rearing, is essential. The wastage also affects the amount of culling of females that he could do. However, the contribution of the culling of females to genetic improvement (of the order of 1 gal. a year) [13] is so small that any increase in length of life will not greatly affect the overall improvement.

We have also been discussing the matter only as it affects milk production. However, as Price [6] has recently shown, the production of beef in this country is closely bound up with the wastage in dairy herds. He points out that the present policy of using colour-marking beef bulls depends for its success on the national dairy herds being able to produce an excess of replacements above their own requirements. 'If the actual average milking life of cows in the "national" dairy herd did not extend beyond $2\frac{1}{2}$ years, this policy of colour-marking breeding could not be pursued without serious and certain risk to future milking capacity and economy.' This would seem to be an important contribution on national scale that an increase in the productive life in dairy herds would make.

Summary

1. The present average productive life of the dairy cow is about 4 lactations.

2. An increase in average productive life of one lactation would have a small effect on the herd mean yield, probably raising it by less than 1 per cent.

3. As replacements account for only about 8 per cent. of total milk costs, longevity is of minor importance compared with yield in the commercial herd. It is shown that, at present prices, the increase in profits from an increase of one lactation in average productive life is about equal to those from an increase in milk-yield of 35 gal.

4. The effect of culling on productive life and herd mean yield is considered.

5. At the present time the effect of improvement of longevity on milk production will be small and it will be of importance mainly in providing cross-bred beef stores for beef production.

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CORRELATION BETWEEN CONSTITUTION AND MILK PRODUCTION OF DAIRY COWS

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ONE of the most important results of modern research into the constitution of cattle is the establishment of the connexion between longevity and constitution. None of the herd-book data gives such a secure basis for measuring the constitution of an animal, especially of the cow, as the length of life. Advanced age is usually attained only if the different organs are healthy, co-operating well, and resistant to disease. Especially in regard to high productivity, longevity indicates good constitution.

Even modern herd-books do not give much information about the constitution of our cattle. Of the indications given undoubtedly age and production are the most important. Other items registered, such as resistance to disease, good feeding capacity, &c., are generally subject to less objective estimation. It may be occasionally true that cows showing a short period of production may also have a good constitution, but, on the other hand, herd-book data revealing a long life and a considerable lifetime production almost invariably indicate excellent constitution.

It cannot be denied that a long life is associated with type and food utilization, and also depends upon environmental conditions. It is easy to trace families the members of which attain a long life. There are even differences in this respect between different breeds. We know, for instance, that the Jersey or the Angeln breed has a longer average life than, for instance, the beef breeds, such as the Shorthorn and Aberdeen-Angus. Siglin found that the Swiss Brown breed lives longer than, for instance, the Simmental, the latter of which is a more pronounced dual-purpose breed.

It seems that early maturity is associated with shortened life. A similar tendency may be observed with increasing body-weight. This is also observed among different horse breeds of heavy and light type (compare the Arab, the Hutsul, and the Belgian breeds). We find, of course, exceptions; for instance, in one family of the Hungarian Simmental breed we had families of exceptionally great body-weight combined with very long life. All these observations prove that heredity plays a pre-eminent role so far as constitution, that is longevity, is concerned.

The practical value of developing a better constitution in dairy cattle and of prolonging the period of economic utilization needs no emphasis. It is a well-known fact, and it will suffice to draw attention to just a few items. Throughout the whole world where dairy or dual-purpose cattle are kept under commercial conditions, the average lifetime production of the cows is very unsatisfactory. The average lifetime of dairy cows varies from 6 to 8 years, the latter being very good. This means that only a relatively small percentage of cows reach an economic age from the point of view of production. For instance, in Hungary only 33 per

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cent. of the cows live more than 10 years; the rest are culled before this age. It is also well known that feeding-stuffs sufficient to produce 16,000–20,000 lb. of milk are needed to replace a culled cow by a young heifer. Therefore it is not at all irrelevant whether the cows must be culled after 10 years' utilization or after 4 or 5 lactations. In other words, it pays very well to have high-producing cows showing an average lifetime of at least 12 or 14 years.

There is another very unsatisfactory result of having short-lived cows. It is well known that most dairy and also dual-purpose cows have 4, 5, and even 6 lactations; also that the 1st and 2nd lactations are not economically satisfactory. On the other hand, the 8th and 9th lactations do not show a great drop in productivity compared with the best lactation.

One of the most important questions in dairy-cattle breeding is whether high milk-production involves a shorter life. This is the opinion of a great number of specialists. The correlation between average milk production and length of life has been studied within a population of Hungarian Red Spotted cows (dual-purpose breed of the Simmental type). The correlation coefficient has been found to be $+0{\cdot}15 \pm 0{\cdot}026$. This correlation shows that high milk production is associated with a slight *increase* of age.

Table 1 shows that the shortest life is characteristic of cows with an average yearly production of 1,000–2,000 kg. *It must be taken into consideration that cows of such low production may have been culled too soon.* The greatest age has been attained by the cows giving 4,000–5,000 kg. average annual production. These data show that a higher production does not tend to reduce the age or be harmful to the constitution. On the contrary, the tendency indicates that even cows with a considerable average production (5,000–6,000 kg.) still attain the satisfactory age of nine years. One explanation of this may be that the condition for high milk production is a good constitution, because only cows with excellent digestive organs, blood composition, circulatory system, &c., are able to produce a large quantity of milk.

TABLE 1. *Correlation between Average Milk Production and Age*

*Average mature yearly milk-yield in kg.**	*Number of cows*	*Average age in years* ($M \pm m$)	*Standard deviation in years*
1,000–2,000	66	$7{\cdot}95 \pm 0{\cdot}338$	2·747
2,000–3,000	393	$8{\cdot}48 \pm 0{\cdot}134$	2·658
3,000–4,000	516	$8{\cdot}85 \pm 0{\cdot}112$	2·548
4,000–5,000	239	$9{\cdot}36 \pm 0{\cdot}148$	2·297
5,000–6,000	79	$9{\cdot}18 \pm 0{\cdot}270$	2·403
6,000–7,000	15	$9{\cdot}17 \pm 0{\cdot}659$	2·552

* 1 lb. = 0·453 kg. 1,000 kg. = 2,200 lb. or 220 gallons.

The data show clearly that under careful management high production does not involve premature body breakdown. Difficulties in breeding (*Paresis puerperalis, Retentio secundinarum*, &c.) are observed

especially in herds where the protein-content of the feed cannot be entirely transformed into milk. If the assimilatory capacity of the cows is well developed, such difficulties are less pronounced. Similar results have been observed by Stockklausner [1], Schäper [2], and others.

A great drawback of a short lifetime is also the reduced possibility of selection.

Considering the above statements and experimental results, *selection should aim at attaining an average age of 12–15 years, combined with good food-utilization capacity and good physical condition at this age.*

This goal is not easy to reach. Some help in selection may be given by the fact that longer-lived cows have a greater number of calves. At the same time, more attention should be given to the desirable environmental conditions (healthy rearing, pasture, natural conditions as regards feeding, &c.).

The other possibility is to keep the bulls much longer in order to facilitate selection for long life on the sire side. Finally, stock bulls should be selected as far as possible out of bull calves descended from cows having already completed a satisfactory lifetime production and having attained a good age.

Summary

It has been found that heredity plays a great role in the development of longevity. In the Hungarian Red Spotted breed (of the Simmental type) only 33 per cent. of the herd-book cows reach an age of over 10 years. The highest age has been attained by cows giving an average annual production of 4,000–5,000 kg. of milk. High milk production involves a good constitution. The correlation coefficient between milk production and age is $+0{\cdot}15 \pm 0{\cdot}026$. The goal should be to breed cows capable of living 12–15 years, by selecting the bulls out of calves descended from cows having attained a high lifetime production and advanced age. More attention should be given to the environment; and bulls should be kept much longer in order to secure additional selection on the sire side.

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THE COMPOSITION OF SOME COASTAL PASTURES IN NEW SOUTH WALES AND ITS RELATIONSHIP TO MILK PRODUCTION

PART I. COMPOSITION OF PASTURES

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Climate and soil.—STUDIES of seasonal changes in the chemical composition of pastures in Australia, which have been made both in the winter-rainfall belt of South Australia [1] and in the summer-rainfall area of central Queensland [2], have shown the same general cycle as was obtained by Woodman in England [3]. Under both South Australian and English conditions close grazing tended to maintain a higher protein level and generally better composition of the pasture, accompanied by a decline in the quantity of herbage produced when the intensity of the grazing became too severe.

No similar studies have been made of the pastures of the coastal areas of New South Wales, on which an important dairy industry has been established. From consideration of the monthly temperature and rainfall figures, this should be an ideal area for grassland production. Since the yield per cow is seriously lower than in other countries with apparently similar environmental conditions, the work reported here was undertaken in an attempt to assess the extent to which the composition of the pasture was responsible.

The field work was undertaken on the Kameruka Estate, Bega, on the south coast of New South Wales.

Climatic Data for Bega, 36°40′ S. lat. 149°49′ E. long. 50′*

	Jan.	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*	*Year*
Mean max. temp.	81·3	82·1	79·0	74·7	68·1	63·4	62·7	65·8	70·8	74·4	76·8	79·6	..
Mean min. temp.	57·3	57·9	54·2	47·6	41·1	36·8	34·6	36·2	41·4	46·5	50·6	55·2	..
Average rainfall . (In points. 100 points = 1 in.)	346	351	387	215	285	339	243	194	218	244	199	312	3333

* Mean figures for all years recorded from C.S.I.R., 1933, Pamphlet No. 42.

The apparent uniformity of the rainfall distribution masks the most serious drawback of the climate, namely, the very irregular way in which the rainfall is actually received. In the year under consideration, out of 22 in. of rain received, 21½ in. occurred in three main falls. The Kameruka Estate itself is in rolling country 300 to 600 ft. above sea-level, and 12 miles inland from Bega. The climate is mild apart from heavy frosts in the valleys during the winter. The average rainfall for the estate is 26·38 in., or 7 in. less than that at Bega.

The soil is derived from granite, and is podsolized, acid, and low in phosphate. The grey-brown surface soil rests on a great depth of decomposed granite, the B horizon generally being very poorly developed

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except in the little valleys where the dual effects of added moisture and surface wash have combined to develop a meadow soil much richer in organic matter and with a tendency to peat formation in wetter places.

Pastures investigated.—(*a*) Hill pastures consisting of such native perennials as Kangaroo grass (*Themeda australis*), Wallaby grass (Danthonia spp.), Love grass (*Eragrostis leptostachya*), and Flat weed (*Hypochaeris radicata*) with diminishing quantities of Spear grass (Stipa spp.), Windmill grass (*Chloris truncata*), Plume grass (*Dichelachne sciurea*), and Redleg grass (*Botriochloa decepiens*); and an associated flora of ephemeral weeds and grasses including the annual clovers, ball clover (*T. glomeratum*), and yellow suckling clover (*T. dubium*).

(*b*) 'Improved' hill pastures—of the same general character—which have had subterranean clover, ryegrass, and phalaris sown through the natural pasture, and top-dressing with superphosphate. In the pastures sampled, the contribution from the introduced grasses was only small.

(*c*) The valley pastures, where under better soil and moisture conditions the introduced species *Paspalum dilatatum* has largely assumed control. The samples taken for analysis consisted entirely of paspalum.

(*d*) The sown pastures are on small areas, usually old cultivation paddocks, that have been sown down to introduced species. They consist largely of subterranean clover with smaller amounts of ryegrass and phalaris (*Phalaris tuberosa*). Weeds, especially *Plantago lanceolata*, were occasionally important contributors to the herbage.

Owing to the closely grazed condition of the pastures, accurate botanical analysis was almost impossible, but for two periods when a number of species were in head a simple examination was made (Table 1).

TABLE 1. *Approximate Botanical Composition of Three of the Pasture Types (Expressed as per cent. by Weight of the Material Collected)*

Pasture type	*Natural pasture*		*Improved pasture*		*Sown pasture*	
Date	*6.10.44*	*10.11.44*	*6.10.44*	*10.11.44*	*6.10.44*	*10.11.44*
Perennial grasses	81·8	34·1	37·4	28·6	..	..
Mainly leaves but including seed heads of						
Stipa	..	3·1	..	0·6	..	..
Danthonia	..	2·1	..	1·3	..	..
Dichelachne	..	..	1·2	..	..	..
Ryegrass, perennial and Wimmera	..	..	15·3	9·8	4·3	9·2
Phalaris tuberosa	..	..	..	..	1·4	0·4
Annual grasses	3·6	34·3	3·4	11·6	20·4	10·6
inc. Vulpia spp.	..	33·2	3·4	4·2	4·7	10·6
Clovers	0·5	8·5	33·0	40·2	59·0	61·4
inc. *T. glomeratum* and *T. dubium*	..	5·3	0·7	7·9	0·6	2·1
Glycine tabacina	0·2	3·0	1·3	2·7	..	..
T. subterraneum	0·3	0·2	31·4	29·6	58·4	59·3
Miscellaneous herbs	12·0	19·0	10·8	7·0	13·0	14·9
Rubbish, dust, &c.	2·2	3·9	0·2	2·8	2·0	3·6

Sampling and analysis.—The samples of herbage were obtained from the pasture by the procedure of the sub-committee of the A.E.A. [4]. As quickly as possible after plucking, and in usually less than an hour, a sub-sample of 50 gm. was taken for carotene determination. This was placed in a dark glass bottle containing 20 per cent. aqueous KOH, stoppered and shaken to ensure complete penetration of the potash into the tissues. Preliminary work showed that this procedure completely eliminated loss during transport and storage prior to analysis. The remainder of the sample was dried in a hot-air oven before packing for transit to the laboratory.

Five constituents were determined on the samples: crude protein, crude fibre, calcium, phosphorus, and carotene, the determination of the first four being on the dried sample. Standard methods were used for crude fibre and crude protein. Calcium and phosphorus were determined after ashing by precipitation as oxalate and molybdate respectively. Carotene was determined by the quantitative chromatographic method of Austin and Shipton [5] using a magnesium-oxide column and a Pulfrich photometer.

Chemical Composition of the Pastures, and its Variation through the Year

The chemical composition of the three groups of pasture are given below. The figures quoted are the means of the three replicates in each case. A brief description of the appearance of the pasture on each occasion is included.

TABLE 2. *Changes in the Composition of* Natural Pasture *throughout the Year. Chemical Composition of the Dry Matter*

Sampling date	*Description*	*Crude protein per cent.*	*Crude fibre per cent.*	CaO *per cent.*	P_2O_5 *per cent.*	*Carotene p.p.m.*
23.4.44	Poor condition 1½ in. high. Brown with a green tinge due to germination of annual species	8·14	..	..	..	44·7
25.5.44	The perennial grass tufts showed a fresh green shoot 1–2 in. long. Annual grasses developing well . . .	13·62	23·60	0·70	0·28	118·3
24.6.44	Pastures fairly green although thin and bare. Generally about 1 in. high with some shoots to 2–2½ in. . . .	13·42	22·56	0·57	0·42	125·0
28.7.44	Sparse and drying out. Perennials checked by frost. Annuals growing, but thin and lacking bulk. All less than 2 in.	9·97	25·14	0·65	0·31	51·5
6.10.44	At peak of spring flush. Showing signs of drying out. Considerable increase in quantity but in general not so green. Some species coming into head	9·56	25·11	0·51	0·33	104·3

TABLE 2 (*cont.*)

Sampling date	*Description*	*Crude protein per cent.*	*Crude fibre per cent.*	CaO *per cent.*	P_2O_5 *per cent.*	*Carotene p.p.m.*
10.11.44	Pasture drying out. Most of the grasses and weeds seeding. Seed stalks rather thin and spindly, from 3 in. to 1 ft. high	9·06	27·21	0·67	0·37	57·6
11.12.44	Generally in very bad state. Some perennial grasses and glycine clover were green and shooting new leaves, but pasture as a whole short owing to grasshopper attack . .	6·81	26·14	0·45	0·25	28·7
23.1.45	Pasture showing good green shoot. Persistently grazed and only 1–2 in. high. Some annuals germinating . .	13·30	27·34	0·48	0·49	209·0
20.2.45	Perennial tufts green and developing well, but material was not lush. Generally in good condition . . .	10·56	26·65	0·50	0·30	251·0
20.4.45	Pasture very green. Good leaf development on perennial clumps. Not so much feed coming from the annuals, the weeds contributing well .	10·78	27·28	0·47	0·33	157·6
	Average for samples included in statistical analysis . .	10·52	25·67	0·56	0·34	128·8

TABLE 3. *Changes in the Composition of* Improved Pasture *throughout the Year. Chemical Composition of the Dry Matter*

Sampling date	*Description*	*Crude protein per cent.*	*Crude fibre per cent.*	CaO *per cent.*	P_2O_5 *per cent.*	*Carotene p.p.m.*
23.4.44	Poor conditions, 1½ in. high, with green tinge due to germination of annual species and subterranean clover. The latter too small to contribute appreciably to the sample .	8·14	..	..	..	48·4
25.5.44	Not grazed heavily, and showed growth 2–3 in. high. Sub. clover on average ½–1 in. high	15·11	..	0·79	0·34	138·1
24.6.44	1½–2½ in. high. The annual clovers and glycine clover are common . . .	14·64	..	0·97	0·60	158·5
28.7.44	Not advanced much on previous sampling; sparse and below 2 in. Sub. clover also not showing much development. Pasture drying out . .	11·39	..	0·87	0·40	57·6

TABLE 3 (*cont.*)

Sampling date	*Description*	*Crude protein per cent.*	*Crude fibre per cent.*	CaO *per cent.*	P_2O_5 *per cent.*	*Carotene p.p.m.*
6.10.44	At peak of spring flush. Annual clovers better developed than in natural pasture. Dwalganup strain of sub. clover seeding, Mt. Barker strain still vegetative . . .	12·18	..	1·06	0·42	122·7
10.11.44	Pasture as a whole drying out. Plenty of bulk, but rather brown, and becoming harsh. Grasses and clovers gone to seed	10·58	..	1·06	0·44	57·6
11.12.44	Generally in poor state. Clover dried and very brittle; annuals dry, dead and brittle; perennial grasses greening and showing shoot-development. Hypochaeris doing well	9·06	..	0·94	0·31	25·3
23.1.45	Showing good growth especially perennial grasses—2–3 in. high. Some sub. clover germinated but too low to pluck. Sample collected principally Hypochaeris and perennial grasses . .	14·24	..	0·53	0·54	235·0
20.2.45	Perennial species, particularly Eragrostis and Chloris coming away well. Sub. clover growing but still not very high. Green and 2–3 in. high generally	11·05	..	0·80	0·36	262·0
20.4.45	Pasture green and looked well but bulk of material harsh and lacking succulence. The sub. clover somewhat yellowish. Perennials and weeds producing most feed . .	11·20	..	0·56	0·35	142·6
	Average for samples included in statistical analysis . .	11·75	..	0·84	0·42	132·9

TABLE 4. *Changes in the Composition of* Sown Pasture *throughout the Year. Chemical Composition of the Dry Matter*

Sampling date	*Description*	*Crude protein per cent.*	*Crude fibre per cent.*	CaO *per cent.*	P_2O_5 *per cent.*	*Carotene p.p.m.*
24.6.44	In good condition, mainly consisting of a thick mat of sub. clover and Phalaris with some rye, about 1½–2 in. high. As a whole, juicy and succulent.	21·20	..	1·24	0·89	224·8
28.7.44	Sub. clover coming away well, although variable in distribution. Up to 3–4 in. high .	18·90	14·05	1·43	0·63	193·5

TABLE 4 (*cont.*)

Sampling date	*Description*	*Crude protein per cent.*	*Crude fibre per cent.*	*CaO per cent.*	*P_2O_5 per cent.*	*Carotene p.p.m.*
6.10.44	Persistently grazed; height of sub. clover not more than 1–2 in. high. Still vegetative. Appreciable weed herbage was present, and annual grasses .	17·08	18·05	1·50	0·65	207·5
10.11.44	Browning off and seeding. A straggly assortment of seeding stalks of grasses, Hypochaeris, and *Plantago lanceolata* with rather dense undergrowth containing also sub. clover . . .	13·66	22·29	1·55	0·65	95·3
11.12.44	Badly browned off, with hardly any green to be seen. Both grasses and legumes had attained maturity and dried out. Sample taken predominantly sub. clover 'hay'	9·83	23·05	1·35	0·37	5·2
23.1.45	Area shut up from grazing. *P. lanceolata* 3–4 in. high formed 90 per cent. of the sample collected. Sub. clover had germinated but too low to collect	21·90	19·83	1·72	0·88	366·8
20.2.45	Sub. clover coming away well. Low-lying or shady areas showed good leaf-development of sub. clover but in drier portions *P. lanceolata* was dominant. Paddock still closed, av. height 2–3 in.	15·45	16·47	1·74	0·53	334·0
20.4.45	In good condition. Sub. clover 2–4 in. high and dominating whole area. Some Phalaris in head, and formed 3–5 per cent. of the herbage . .	18·85	16·83	1·50	0·69	288·0
	Average for samples included in statistical analysis . .	18·36	18·65	1·50	0·66	212·9

TABLE 5. *Changes in the Composition of* Paspalum *throughout the Year. Chemical Composition of the Dry Matter*

Sampling date	*Description*	*Crude protein per cent.*	*Crude fibre per cent.*	*CaO per cent.*	*P_2O_5 per cent.*	*Carotene p.p.m.*
23.4.44	Green and fresh, closely cropped to 1–1½ in. . .	11·32	..	..	..	123·1
25.5.44	Fresh and green, with leaf development up to 3 in. long	11·64	22·75	0·71	0·31	150·1
24.6.44	Still green and fresh. The valleys waterlogged by seepage. On mounds grass tended to the brown and withered at tip, green and lush in depressions.	12·33	22·51	0·85	0·38	143·2

TABLE 5 (*cont.*)

Sampling date	*Description*	*Crude protein per cent.*	*Crude fibre per cent.*	CaO *per cent.*	P_2O_5 *per cent.*	*Carotene p.p.m.*
28.7.44	Extensively damaged by frost; rather brown and on the whole showing little growth.	9·45	20·56	0·71	0·34	49·8
6.10.44	Very green and growing vigorously	16·26	20·89	0·70	0·55	357·0
10.11.44	Green and growing well .	14·27	21·23	0·80	0·50	275·0
11.12.44	Had been eaten almost bare by grasshoppers to ½–1 in. high, and badly yellowed . .	9·79	23·37	0·45	0·32	104·9
23.1.45	Dark green, growing well and from 1–2 in. high . .	13·03	31·53	0·54	0·55	262·0
20.2.45	Growing well, 1–2 in. high. A thick uniform mat of dark green	11·66	28·16	0·58	0·40	383·0
20.4.45	Growth green and lush, although cropped very closely. Some areas fresh, others browned slightly . .	12·90	21·92	0·50	0·39	235·5
	Average for samples included in statistical analysis . .	12·27	23·66	0·63	0·42	238·2

TABLE 6. *Standard Errors and Difference for Significance*

	Crude protein	*Crude fibre*	CaO	P_2O_5	*Carotene p.p.m.*
Standard error of the mean of three determinations, expressed as a percentage of the grand mean.	4·15	1·96	2·95	2·52	6·02
Difference for significance at 5 per cent. point between two means of three determinations ('monthly' samples) . .	0·88%	1·31%	0·10%	0·40%	20·5%
Difference for significance at 5 per cent. point between means of all samples for each pasture	0·31%	0·50%	0·04%	0·02%	13·7%

The results show that there is some association between the level of protein and the levels of both phosphorus and carotene. These associations have been found by other workers. In this case, however, there does not appear to be the negative association between crude fibre and crude protein that has been commented on by others, except possibly in the case of the sown pasture, dominated by subterranean clover. The paspalum showed no such similar effect.

The correlation coefficients between protein and the other constituents of the herbage for each pasture type are given in Table 7.

As can be seen, significant correlation coefficients with carotene, and the very significant coefficients with phosphorus are obtained for both paspalum and for the sown pasture. These possibly reflect the relationship of carotene and phosphorus with protein in the metabolism of the

TABLE 7. *Correlation Coefficients between Protein and the Other Constituents*

	Correlation coefficients with			
	Carotene	*Crude fibre*	CaO	P_2O_5
Natural pasture .	0·5569 N.S.	0·4283 N.S.	0·2577 N.S.	0·5774 N.S.
Improved pasture .	0·4940 N.S.	. .	0·2594 N.S.	0·5765 N.S.
Sown pasture . .	0·7655*	−0·6025?	0·0775 N.S.	0·9041†
Paspalum . .	0·7320*	0·0593 N.S.	0·2863 N.S.	0·8241†

(N.S. = Not significant; * = significant at 5 per cent. point; † = significant at the 1 per cent. point; ? = approaching significance.)

plant. They have been observed before in pure species, or in mixed stands where all or most of the species react similarly to climatic changes. For the natural and improved hill pastures, the mixture of species and their differing times of maturity apparently prevent any such relationships from developing.

The analysis of variance of the foregoing data (see Appendix, p. 72) shows the sampling procedure to be satisfactory for these types of pasture, the variance between replicates being satisfactorily low and not significant. The standard error of the mean of three replicates, expressed as a percentage of the mean for each constituent, has been calculated to allow comparison (Table 6). The figure for carotene is higher than those for the other nutrients, probably owing to the speed with which it is oxidized in the plucked grass during sampling. It is still low enough to allow comparison of the carotene-content on different sampling dates. The differences necessary for significance at the 5 per cent. point between the different sampling dates for each nutrient considered, and between each pasture type, are also given in Table 6. The analysis of variance for some nutrients did not include all the data on which Tables 2–5 are based, because in some of the earlier samplings one or more of the triplicate samples for one or other pasture type were lost in transit, whilst sampling of the sown pasture did not begin until 2 months after the natural and improved pastures were first sampled. The mean figure quoted for each pasture type is consequently the mean obtained from all samples considered in the analysis of variance.

The validity of the differences shown between the compositions of the different pasture types on the various sampling dates can be studied by comparison of the differences given in Table 6 with the data in Tables 2–5. Thus for protein, the standard error of single determination was 0·54 per cent. crude protein, giving a difference for significance between two values, each a mean of three such determinations, of 0·88 per cent. at the 5 per cent. point and 1·11 at the 1 per cent. point. Comparing the average figure for all monthly samples, the difference between the natural and the improved pastures is 1·23 per cent. protein, which is highly significant (at the 0·1 per cent. point).

The relationship between the pastures is not always the same from month to month. The sown pasture is always better than the other

three, on some dates containing twice the protein-content of the natural pasture, but the natural and the improved pastures are sometimes better, sometimes worse, than the paspalum.

The crude-fibre content shows similar changes, reflecting in part the growth cycles of the component species of each pasture. Thus the sown pasture (largely subterranean clover) is significantly lower in crude fibre than the paspalum in April and June, significantly higher in July and October, and significantly lower again the following January, February, and April. Comparison with the natural pasture shows the sown pasture to be significantly lower in crude fibre on every sampling date. Considering the mean figures for all sampling dates the natural pasture is significantly higher than the paspalum, which is in turn significantly higher than the sown pasture. There does not appear to be much evidence in these pastures for the negative association between crude fibre and crude protein shown by other results, reported in the literature [1, 2, 3], except possibly in the case of the sown pasture. Over the period concerned, the natural pasture remains surprisingly constant in fibre-content, despite the fact that many species ran up into head. This relative constancy may be due in part to the very close grazing to which the area was subjected, and partly to the complex mixture of grass and weed species of which it is constituted. The paspalum shows the interesting feature of a marked rise in fibre-content during the time when it would normally be running up into head. Although in this case it was kept heavily grazed and consistently short, the fibre development characterizing its usual physiological stage is still evident although the protein-content at this time was not at its lowest.

The superiority of the sown pasture to all other types becomes obvious when the calcium and phosphorus are considered. At each sampling date the phosphorus-content of the sown pasture is significantly better than that of any of the three other pastures. It is twice as high in June as is the paspalum, and twice as high in June, October, and April as is the natural pasture. The mean figure for the year is nearly twice as high as that for the natural pasture, and one and a half times as high as the figures for paspalum or the improved pasture. The calcium-content of the sown pasture is even more markedly superior. Like the phosphorus-content it is higher on every sampling date than that of every other pasture, it is twice as high on two occasions and three times as high on one occasion (January) as the improved pasture, which is the next best source of calcium. On no sampling date does the natural pasture ever contain half as much calcium as does the sown one. The calcium figure for paspalum lies in between those of the natural and improved hill pastures.

The effect of superphosphate and subterranean clover in improving hill pasture is also shown by the calcium and phosphorus contents, phosphorus being significantly higher on eight of the nine sampling dates, and not significantly different on the ninth. The calcium-content of the improved pasture is significantly higher than that of the natural pasture on four dates, twice as high in October and December, and not different on the other three.

The sown pasture is much superior as a source of carotene than either the natural or improved pastures, and is higher on every sampling date except December (midsummer), when it was brown and showed no growth. The improved pasture was better than the natural only on two occasions and was not significantly different over the year.

In the carotene figures, paspalum showed the effects of better moisture conditions and formed a good source of carotene except in winter (July sample) when it was very brown due to frost damage. The sown pasture was higher in the winter months and lower in the summer months than paspalum; the mean for all dates, however, was significantly lower than that for paspalum.

Discussion

The relationship of the pasture compositions given above to the nutrition of the dairy herds grazing them will be considered in Part II. Here it is desired to draw certain comparisons with data from the literature for other pastures.

TABLE 8. *Data for Other Pastures Sampled at Monthly Intervals*

	Crude protein	*Crude fibre*	CaO	P_2O_5
Waite Institute, South Australia				
Natural pasture, unmanured	3·1–15·5 (7·96)	17·0–40·0	1·23–1·92	0·12–0·48
Natural pasture, receiving 2 cwt./acre superphosphate [7] . . .	3·6–16·9 (9·71)	14·4–38·0	1·01–2·16	0·19–0·69
Cambridge, England				
Lightland pasture, cut at monthly intervals [1] .	13·6–25·9 (20·2)	13·2–18·2 (16·92)	1·31–1·86 (1·67)	0·89–1·17 (0·98)
Wood's Point, South Australia				
Irrigated pastures, rotationally grazed at monthly intervals [6] . . .	19·1–29·3	..	..	0·85–1·34
Winton, Queensland				
Mitchell grass pasture, sampled monthly, but pasture ran up to head, and was not kept closely grazed [3] . . .	4·6–16·6	26·3–35·2	0·29–0·35	00·5–0·21
Bega, N.S.W.				
Natural hill pasture . .	6·8–13·6	22·5–27·3	0·45–0·70	0·25–0·49
Improved hill pasture .	8·1–15·1	..	0·53–1·06	0·31–0·60
Paspalum . . .	9·5–16·3	20·6–31·5	0·45–0·85	0·31–0·55
Sown pasture, mainly sub. clover	9·8–21·9	14·0–23·0	1·24–1·74	0·37–0·89

Comparison of the natural pasture at Bega with that of related botanical composition at the Waite Institute, South Australia, shows the

general similarity of the two. In the samples from Bega the intense grazing practised has prevented the protein from falling so low, or the fibre from rising as high, as the comparative figures from the Waite Institute. The calcium in the South Australian samples is much higher than in those reported here, the phosphorus falling within the same range. The effect of superphosphate in encouraging legume growth has produced about the same increase in protein in each case.

By contrast, the sown pasture resembles much more closely the irrigated pastures at Wood's Point, or those at Cambridge, in having higher contents of protein and calcium and less fibre. The figures for phosphorus reported here are lower than the other two, probably in response to the very low phosphate-content of the soil.

Paspalum, whilst distinctly better than the natural pasture in all respects, is inferior to the sown pasture at eight of the ten sampling dates, despite its more favourable situation. The natural pasture, even when improved by superphosphate and seeding with subterranean clover, does not compare with the sown pasture as a source of nutrients. Here it appears to be better than its counterpart at the Waite Institute perhaps because it is better grazed, and because the rainfall is a little more evenly distributed, but the constituent grasses do not possess the ability to produce herbage of the nutritive quality as the introduced species, and as long as they remain dominant features of the pasture, it seems unlikely that much improvement in pasture quality can be expected. The marked improvement that subterranean clover and superphosphate have produced in other parts of New South Wales has in the authors' experience been accompanied by a much greater dominance of the introduced species, which have crowded out the native grasses much more effectively than at Kameruka. The value of the introduction of paspalum to the coastal pastures of New South Wales lies in the fact that not only does it produce herbage of better quality than the native species, but that even under poor conditions it is an aggressive colonizer and will effectively compete with the native species, particularly on the moister and more favoured spots.

Following the work of Fagan and Jones [8] at Aberystwyth, it has been commonly assumed that most species if kept short give herbage of relatively similar composition. The studies reported here suggest that this is not always so, and that even under close grazing the native grasses and paspalum show a nutritive value seriously lower than can be obtained from pastures sown to other species.

The variations in composition shown between the different sampling dates are due principally to the interaction of the seasonal temperature cycle and the markedly seasonal rainfall incidence on the different species. Thus the 11 in. of rain received in May 1944 was responsible for a sharp rise in the protein-content of the natural and improved hill pastures, due to its effect on the ephemeral and weed flora, but had little effect on paspalum. By contrast the $5\frac{1}{2}$ in. of rain received in January 1945 caused a sharp rise in the protein-content of paspalum, and an even more marked effect on that of both types of hill pasture. The effect of this rain did not persist long, due probably to the greater evaporation at the higher temperatures obtaining in summer.

In general the introduced cool-climate grasses and legumes developed better under the cooler conditions, whereas the winter frosts suppressed the development of paspalum and native perennial grasses. On the other hand, the warm conditions in spring and early summer bring on maturity in the introduced grasses and clovers whilst encouraging the growth of the native perennials and paspalum. The introduced species such as subterranean clover and ryegrass considerably improve the feeding-value of the pastures during the cooler months, due both to better composition and to the ability to grow at lower temperatures. During the hot and often dry summer months the bulk of the feed is produced on the paspalum flats and also by native perennial grasses, but their nutritive value is not high even at its best.

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Appendix overleaf

APPENDIX

Analysis of Variance

Source	*Protein*		*Crude fibre*		*Phosphoric acid* (P_2O_5)		*Calcium oxide* (CaO)		*Carotene*	
	D.F.	*Mean square*	*D.F.*	*Mean square*	*D.F.*	*Mean square*	*D.F.*	*Mean square*	*D.F.*	*Mean square*
Between types	3	165·57‡	2	333·39†	3	0·31†	3	4·42†	3	71,102·1†
,, months	6	51·61‡	6	40·42†	6	0·10†	6	0·09†	6	111,902·8†
,, replicates	2	0·06 N.S.	..	..	..	..	..	..	2	109·6 N.S.
Type × months	18	10·72‡	12	24·02†	18	0·10†	18	0·05†	18	9,905·3†
,, × replicates	6	0·15 N.S.	..	..	..	..	..	..	6	124·7 N.S.
Month × replicate	..	..	..	..	..	..	..	..	12	510·8 N.S.
Error	48	..	42	..	56	..	56	..	36	..
Total	83	..	62	..	83	..	83	..	83	..

(N.S. = Not significant; * = significant at the 5 per cent. point; † = significant at the 1 per cent. point; ‡ = significant at the 0·1 per cent. point.)